State of California
THE RESOURCES AGENCY
Department of Water Resources

BULLETIN No. 118-2

LIVERMORE AND SUNOL VALLEYS

EVALUATION OF GROUND WATER RESOURCES

Appendix A: GEOLOGY

AUGUST 1966

HUGO FISHER	EDMUND G. BROWN	WILLIAM E. WARNE
Administrator	*Governor*	*Director*
The Resources Agency	State of California	Department of Water Resources

FOREWORD

The ground water basins of Sunol and Livermore Valleys have played an important role in the water supply of the San Francisco Bay area since the late 1800's. Since 1945, extractions have exceeded recharge and resulted in a reduction of ground water in storage, cessation of subsurface outflow to the Niles Cone, and degradation of water quality in portions of the Livermore Valley ground water basin.

Ground water geology presented in this Appendix summarizes the current state of geologic knowledge of the Sunol and Livermore Valleys and is an extension of geologic knowledge gained from a previous ground water investigation of Livermore Valley conducted by the Department between 1959 and 1962 and published in January 1964 as "Alameda Creek Watershed above Niles, Chemical Quality of Surface Water, Waste Discharges and Ground Water". The Appendix presents the geology of the water-bearing sediments in considerable detail to better explain the origin, occurrence, and movement of ground water within the basins.

William E. Warne

William E. Warne, Director
Department of Water Resources
The Resources Agency
State of California

TABLE OF CONTENTS

FIGURES

PLATES

ACKNOWLEDGEMENT

The following individuals were especially helpful in sharing their knowledge and providing valuable data during the course of this study. Their help is gratefully acknowledged.

Mr. Fred Woods, President, California Rock and Gravel Company

Mr. George Kelly, Plant Superintendent, California Rock and Gravel Company

Mr. George G. Jamieson, President, Rhodes and Jamieson

Mr. George Hampton, Pacific Cement and Aggregates

Mr. Arnold Abrott, Henry J. Kaiser Company

Mr. R. A. Fones, Acme Drilling Service

Mr. R. W. Tiecke, California Water Service Company

Mr. Carl T. Crowell, Parks Air Force Base

Mr. Carl T. Forsberg, Lawrence Radiation Laboratory

Mr. Harold Wollenberg, Lawrence Radiation Laboratory

Mr. Douglas McCloud, City of Pleasanton

Mr. William Black, Volk-McLain and Associates

Mr. Charles Hughes, San Francisco Water Department

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES

EDMUND G. BROWN, Governor
HUGO FISHER, Administrator, The Resources Agency
WILLIAM E. WARNE, Director, Department of Water Resources

ALFRED R. GOLZE', Chief Engineer
JOHN R. TEERINK, Assistant Chief Engineer

--------------0--------------

SAN FRANCISCO BAY DISTRICT

Charles A. McCullough . . . . District Director
Jerry D. Vayder . . . . Chief, Planning and Investigations Section

This investigation was conducted
under the supervision of

Donald J. Finlayson . . . . Senior Engineer, Water Resources

by

William R. Hansen . . . . Associate Engineering Geologist

assisted by

James V. Vantine . . . . Assistant Engineering Geologist

CALIFORNIA WATER COMMISSION

RALPH M. BRODY, Chairman, Fresno

WILLIAM H. JENNINGS, Vice Chairman, La Mesa

JOHN W. BRYANT, Riverside

JOHN P. BUNKER, Gustine

IRA J. CHRISMAN, Visalia

JOHN J. KING, Petaluma

EDWIN KOSTER, Grass Valley

NORRIS POULSON, La Jolla

MARION R. WALKER, Ventura

-----0-----

WILLIAM M. CARAH
Executive Secretary

ORVILLE ABBOTT
Engineer

cease. This condition, along with the reuse of water, results in an unfavorable salt balance. The recycling of ground water has noticeably degraded the quality of well water in the eastern portion of the Santa Rita subbasin.

The water supply necessary to serve the future population will be met partly by ground water. The threat to the quality of ground water, the direct importation of water, and the completion of Del Valle Reservoir are factors which will soon make it desirable to formulate a comprehensive plan for conjunctive operation of ground and surface water supplies. Before any such plan can be formulated, the geology of the ground water basins and the occurrence and movement of ground water within the basins must be thoroughly understood.

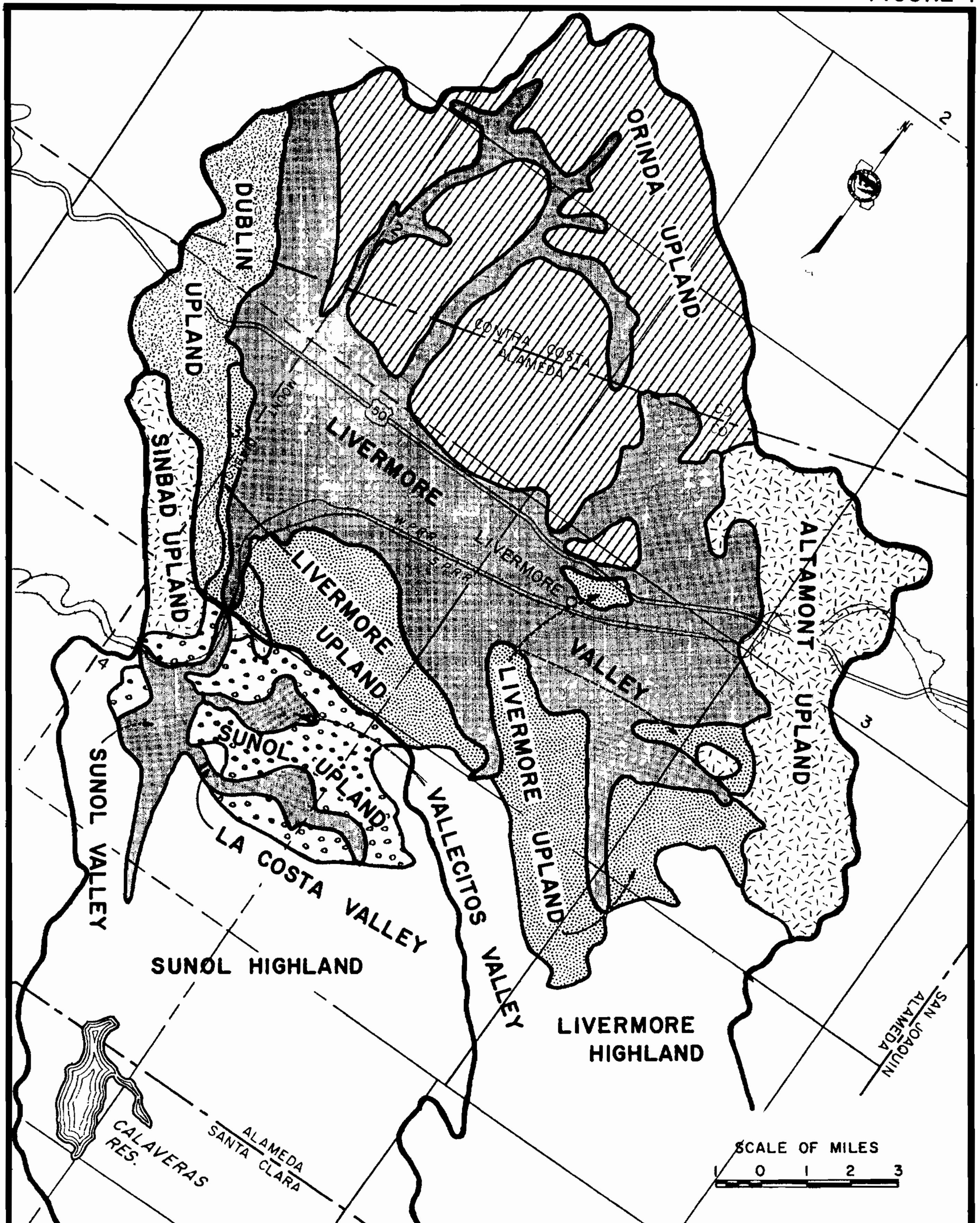
The objective of planned utilization studies is to provide local agencies with practical plans to conjunctively operate surface water facilities with ground water resources. This appendix is the first step in reaching that objective.

Purpose

This appendix generally describes the geology of the watershed which is tributary to Alameda Creek above Sunol Dam. Particular emphasis has been placed on the ground water geology of the water-bearing sediments beneath the surface of both Livermore Valley and Sunol Valley. This information will be the basis for a study which will evaluate the ground water resource of the area. The ground water resource evaluation to be presented in Bulletin 118-2 will summarize hydrologic and geologic characteristics of the area and will outline the operational plans which should receive detailed study.

Scope

This appendix reports on an extension of the geologic knowledge gained from a previous ground water investigation of Livermore Valley conducted by the Department between 1959 and 1962 and published in January 1964. The report, entitled "Alameda Creek Watershed above Niles, Chemical Quality of Surface Water, Waste Discharges, and Ground Water", examined in detail the ground water conditions in the western portion of Livermore Valley; therefore, little additional work was necessary in the western portion. Additional study was conducted in the southern and eastern portions of Livermore Valley and in the Sunol Valley ground water basin. Knowledge gained during this additional study and during the previous investigation is presented in this appendix. The geology of the water-bearing sediments has been presented in considerable detail to better explain the origin, occurrence, and movement of ground water within the basins.



PHYSIOGRAPHY

CHAPTER II. DESCRIPTION OF DRAINAGE UNITS

The area covered by this report includes that part of the Alameda Creek watershed which lies above Sunol Dam at the head of Niles Canyon and occupies parts of Contra Costa, Alameda, and Santa Clara Counties. It is an elongated area of about 582 square miles oriented northwest - southeast and lies in the Diablo range about 40 miles east of San Francisco and 30 miles southwest of Stockton. The area of investigation contains the Livermore drainage unit and the Sunol drainage unit. The location and extent of the watershed and drainage units, and their relationship to the San Francisco Bay area to the west are shown on Plate 1.

Livermore Drainage Unit

The Livermore drainage unit occupies the northern and eastern portion of the Alameda Creek watershed. The main streams in the drainage unit include Arroyo del Valle, Arroyo Las Positas, Arroyo Mocho, Alamo Creek, South San Ramon Creek, and Tassajara Creek. Arroyo del Valle and Arroyo Mocho are the largest and most important streams because they drain the largest area. All streams converge on the floor of Livermore Valley, join Arroyo de la Laguna, and flow out of the valley to join Alameda Creek in the Sunol drainage unit.

The Livermore drainage unit has been divided as shown on Figure 1, into six physiographic areas named from north to south, Orinda upland, Dublin upland, Altamont upland, Livermore Valley, Livermore upland, and Livermore highland.

Orinda Upland

The Orinda upland includes the gently rolling hills north of Livermore Valley which are largely underlain by soft, essentially nonwater-bearing rocks of the Orinda Formation. These hills gradually increase in elevation toward the northern border of the watershed where resistant Cretaceous rocks reach a maximum elevation of approximately 2,500 feet.

Dublin Upland

The Dublin upland includes the eastern-sloping rugged hills along the west side of Livermore Valley. The upland covers an area about eleven miles long and two miles wide, that is sparsely wooded and supports many small streams that drain eastward into the valley. The southwestern boundary lies along Pleasanton Ridge where the upland reaches a maximum elevation of 1,629 feet.

Altamont Upland

The Altamont upland includes the rolling, grass covered hills bordering Livermore Valley and Livermore upland on the northeast. The upland covers an area eleven miles long and about four miles wide that is underlain largely by sandstone and shale. The middle portion of the upland reaches an elevation of 1,702 at Brushy Peak, but gradually increases in ruggedness and elevation to the south, reaching a maximum there of 2,265 feet.

Livermore Valley.

Livermore Valley includes the lowland portion of the watershed underlain by alluvium. It is an irregularly shaped area averaging about 3 miles in width and extends about 14 miles between Altamont Hills on the east and Pleasanton Ridge on the west. Arms of the valley extend to the south along the channels of both Arroyo Mocho and Arroyo del Valle and to the north along South San Ramon Creek, Alamo Creek, and Tassajara Creek. The floor of the valley slopes gently west at about 20 feet per mile from an elevation of 600 feet on the eastern end to about 300 feet near the southwestern corner.

Livermore Upland

The Livermore upland includes the gently rolling hills underlain by the Livermore Formation present largely south of Livermore Valley. These hills increase in elevation to the south, from the edge of the valley to a maximum elevation of 1,289 feet just north of the drainage divide between the Livermore and Sunol drainage units. Small hilly exposures of the Livermore Formation, present within Livermore Valley and along its western border, are included as part of the Livermore upland.

Livermore Highland

The Livermore highland which occupies the mountainous region south of the Livermore upland is underlain by the oldest rock formations in the area. The terrain in this region is extremely rugged, rising to the south from an elevation of 1,900 feet to almost 4,000 feet at the extreme southern border. Most streams and intervening ridges in this portion of the watershed parallel each other in a northwesterly direction. Arroyo del Valle, Arroyo Mocho, and Arroyo las Positas all begin in the Livermore highland.

Sunol Drainage Unit

The Sunol drainage unit occupies the small, southwestern portion of the Alameda Creek watershed. Streams in the drainage unit include Smith Creek, Isabel Creek, Arroyo Hondo, Alameda Creek, Calaveras Creek, Indian Creek, San Antonio Creek, and Vallecitos Creek. The main tributary streams are Arroyo Hondo and Calaveras Creek. All the streams are tributary to Alameda Creek which flows northward through Sunol Valley at the north end of the drainage unit.

The small Sunol Dam, situated at the northwest end of Sunol Valley, partially ponds Alameda Creek as it enters Niles Canyon on its way to San Francisco Bay. Sunol Dam was constructed as a subsurface, as well as a surface, barrier to the flow of water leaving Sunol Valley. For this reason, Sunol Dam has been adopted as the western limit of the area of investigation. All ground water escaping Sunol Valley must rise to the surface in Alameda Creek and pass over Sunol Dam. Thus, both ground water and surface water leaving the watershed along Alameda Creek can be measured at the dam.

The Sunol drainage unit has been divided as shown on Figure 1, into six physiographic areas, named from north to south, Sinbad upland, Sunol Valley, Vallecitos Valley, La Costa Valley, Sunol upland, and Sunol highland.

Sinbad Upland

The Sinbad upland includes the entire watershed of Sinbad Creek which drains southeast into the north end of Sunol Valley. This densely wooded ravine is seven miles long and one mile wide, and is underlain by relatively hard rocks of

Cretaceous age. The eastern boundary of this unit coincides with Pleasanton Ridge. The western boundary lies along Sunol Ridge where the maximum elevation in the unit of 2,191 feet is reached.

Vallecitos Valley

Vallecitos Valley lies northeast of Sunol Valley and occupies an area of about one square mile. The valley ranges in elevation from about 580 feet at the north end to 323 feet at the south end. It is joined to Sunol Valley along the stream course of Vallecitos Creek by a very narrow strip of alluvium. Vallecitos Creek joins Arroyo de la Laguna about 3/4 of a mile above its junction with Alameda Creek.

La Costa Valley

Prior to 1964, La Costa Valley occupied a narrow area over five miles long underlain by shallow alluvium. In that year, completion of Turner Dam created San Antonio Reservoir which now covers the lower portion of the valley. Only the eastern portion of the original valley area remains above the reservoir and this portion retains the original name.

Sunol Valley

Sunol Valley is by far the largest valley in the Sunol drainage unit. It slopes to the north from an elevation of 350 to 225 feet and is traversed by all the major streams in the drainage unit. The northwestern corner of Sunol Valley, where Alameda Creek leaves the watershed, is the lowest point in the area of investigation.

Sunol Upland

The Sunol upland includes the gently rolling hills underlain by the Livermore Formation. It borders the northern portion of Sunol Valley and surrounds both Vallecitos and La Costa Valleys. The Sunol upland averages over 700 feet in elevation and reaches a maximum of 1,058 at the boundary with the Livermore drainage unit.

Sunol Highland

The Sunol highland borders on the southern portion of Sunol Valley and the Sunol upland and covers the southern three-quarters of the Sunol drainage unit. The region is mountainous and rugged with streams and intervening ridges tending to parallel each other in a northwesterly direction as they do in the Livermore upland. The ridge summits increase in elevation to the south from 1,800 feet at the south edge of the Sunol upland to almost 4,000 feet in the area north of Mt. Hamilton. Arroyo Hondo, Calaveras Creek, and Alameda Creek have their origin in the Sunol highland.

CHAPTER III. GEOLOGIC FORMATIONS

The geologic formations within the Alameda Creek watershed have been divided into two major groups: nonwater-bearing and water-bearing. This broad division is based on the ability of the formation to yield water to wells. The nonwater-bearing group includes formations that yield water to wells in quantities so low as to be useable only for stock watering and very low demand domestic supplies. The water-bearing group includes formations that yield ground water to wells in quantities sufficient to supply the needs of domestic, municipal, agricultural, and industrial users. The ground water basins and subbasins referred to in this chapter are shown on Plate 2 and described in Chapter VI. The areal geology is shown on Plate 3.

Nonwater-Bearing Group

The nonwater-bearing group consists of formations ranging upward in age from Jurassic through Pliocene. Excellent detailed descriptions of these formations are included in publications by Huey[12/], Crittenden[6/], and Hall[9/].

Jurassic Formations

Marine rocks of Jurassic age comprise nearly the entire southern half of the watershed within the Livermore and Sunol highlands. These rocks are the oldest exposed in the area and are mapped as the Franciscan Group. The Franciscan Group is composed primarily of sandstone with smaller amounts of interbedded siltstone and shale. Minor rock types include conglomerate, various colored chert, altered igneous rocks (greenstone) and small irregularly shaped bodies of serpentine.

Cretaceous Formations

Rocks of Cretaceous age are exposed over large areas southwest and northeast of Livermore Valley and south of the valley along the middle reaches of Arroyo del Valle. These rock types consist primarily of sandstone, shale, conglomerate, and siltstone, all of marine origin.

Formations in the lower Cretaceous have been mapped by various workers as Oakland Conglomerate, Niles Canyon, and Horsetown Formations. Upper Cretaceous rocks have been mapped as the Berryessa, Del Valle, Moreno Grande, Panoche, and Chico Formations.

Cretaceous rocks are found in the area only in fault contact with the older Franciscan rocks, but are known elsewhere to unconformably overlie them.

Eocene Formations

Rocks of Eocene age have been mapped in only two small exposures, southeast of Livermore Valley and at the north end of the watershed. These rocks consist of conglomerate, shale, sandstone, and occasional coal seams, and have been described as the Telsa, Tolman, and Tejon Formations.

Miocene Formations

Rocks of Miocene age are exposed over a wide area bordering the two ground water basins on the east, west, and south, and as a narrow strip near the northeast boundary of the Livermore drainage unit. They have been described under a number of formational names within the lower and upper Miocene.

Middle Miocene rocks include marine sandstone, shale, tuffaceous beds, and some chert and are mapped as the Oursan, Claremont, Sobrante, and Monterey Formations.

Upper Miocene rocks include green sandstone, siltstone, shale, conglomerate, tuff, and some coal seams and are divided into the Neroly, Cierbo, Briones, Hambre, and Tice Formations.

Pliocene Formations

Rocks of early Pliocene age unconformably overlie the upper Miocene rocks and include the oldest evidence of continental deposition. Fresh water deposits of sandstone, conglomerate, siltstone, and claystone, with small amounts of tuff and limestone, are exposed as the Orinda Formation located largely north of Livermore Valley. The Orinda is not well indurated, but the abundance of fines in the formations make it essentially nonwater-bearing. The Orinda reaches a thickness of 9,000 feet north of Livermore Valley.[9,pg. 29/]

Water-Bearing Group

The water-bearing group consists of deposits ranging in age from late Pliocene to the present. These deposits were laid down under continental conditions in alluvial fans, outwash plains, and lakes. Plio-Pleistocene sediments comprise the Livermore Formation while the Quaternary (Pleistocene to Recent) deposits comprise the Quaternary alluvium.

Plio-Pleistocene Livermore Formation

Deposits ranging in age from middle Pliocene to lower Pleistocene occur in the Alameda Creek watershed as the Livermore Formation.

The Livermore Formation is prominently exposed over the large area comprising the Livermore upland and Sunol upland. This formation is up to 4,000 feet thick and consists of unconsolidated to semi-consolidated beds of gravel, sand, silt, and clay. Limey concretions are fairly common in its lower portion, and tuffaceous beds are present at its base.

Coarse-grained portions of the Livermore Formation may locally contain boulders up to a foot or more in diameter. The source of the coarser grains is probably the Jurassic and Cretaceous rocks to the south. These grains consist of black to red chert, micaceous sandstone, black shale, and quartzite.

Exposures of the Livermore Formation often appear superficially gravelly and pervious; however, close examination usually reveals an abundance of fines between the coarser grains. This high percentage of interstitial fines appears to be responsible for the inability of the Livermore Formation to transmit water as well as the Quaternary alluvium.

Throughout its outcrop area, the Livermore Formation consistently dips to the north or northwest from 5 to 30 degrees. It lies beneath both La Costa and Vallecitos Valleys at relatively shallow depths, and dips beneath the alluvium of Livermore Valley.

The Livermore Formation stratigraphically overlies the Orinda and older formations with slight angular discordance. However, the contact between the Livermore and Orinda Formations is hidden beneath the alluvium and may lie along the Parks fault.

Quaternary Alluvium

Deposits of upper Pleistocene to Recent age are grouped together as the Quaternary alluvium. No attempt has been made to differentiate the late Pleistocene deposits from those of Recent age, since this distinction is impossible at depth on the basis of drillers' logs.

The Quaternary alluvium consists of stream and lake deposited sediments including various mixtures of gravel, sand, silt, and clay. It is largely unconsolidated and overlies the Livermore Formation in most of the valleys and the Orinda Formation in the northern portion of Livermore Valley.

The exact thickness of the alluvium is difficult to determine because of the similarity in the descriptions of alluvium and underlying formations as reported on well logs. However, well logs vaguely suggest a decrease in the grain size at various depths. The decrease is by no means sharp, but it may generally describe the contact between the two formations. The thickness of the alluvium in Livermore Valley increases gradually from east to west. In the Livermore subbasin, alluvium reaches a thickness greater than 200 feet in only the western portion (the distribution of shallow alluvium is shown on Plate 5). The alluvium probably reaches its greatest thickness of perhaps 700 feet just west of Pleasanton and may be almost this thick in portions of the San Ramon subbasin.

The percentage of sand and gravel aquifers present within the alluvium down to a depth of 300 feet is shown on Plate 5. The thickness of aquifers in the depth intervals 0-100, 100-200, and 200-300 feet are shown respectively on Plates 6, 7, and 8. These diagrams clearly show the course of the streams that were responsible for depositing the sand and gravel within the Quaternary alluvium. Elongated zones of the highest sand and gravel percentages (shown on Plates 6, 7, and 8 by arrows) closely approximate the present courses of Arroyo Mocho and Arroyo del Valle and show that the ancestral portion of these streams was important during deposition of the coarser portions of the upper 300 feet of alluvium. The ancient stream course outlet through San Ramon Valley (Plates 7 and 8), as well as the more recent one along Arroyo de la Laguna (Plate 6), are clearly shown by the thickness contours. The alluvium along the northern border of Livermore Valley is considerably thinner than elsewhere, seldom exceeding 100 feet in thickness, and is generally much finer-grained than that along the southern border (Plate 5). Gravel percentages seldom exceed 20 percent and often diminish to zero.

The fine-grained nature of the alluvium along the northern border of Livermore Valley is the result of deposition by small streams draining from the hills north and east of the valley. These streams carried relatively fine-grained sediments derived from the weathering and erosion of predominately fine-grained Cretaceous and Tertiary rocks. These sediments were deposited as silt or clay beds with occasional lenses and stringers of sand and gravel. In contrast, as mentioned above, the coarse alluvium in the southern portion of Livermore Valley was deposited by the much stronger streams draining from the south, noteably ancestral Arroyo Mocho and Arroyo del Valle.

In the east portion of Livermore Valley, the alluvium is revealed in well logs to be composed of overlapping, inter-fingering lenses, stringers, and sheets of gravel, sand, silt, and clay. Individual layers are not extensive enough to be traced between well logs, apparently because they change their physical nature over very short distances and are no longer recognizable. This heterogeneous nature of the alluvium is largely the result of many small streams depositing the alluvium at the same time.

In the west half of Livermore Valley, ancestral Arroyo del Valle dominated the deposition of alluvium. The extensive gravel layers deposited there alternate with extensive, thick clay beds laid down when lakes were present in the western portion of the valley. The extensive nature of these alternating clay and gravel layers are illustrated on the Section C-C' and D-D' shown on Plate 4. Gravel layers, such as those illustrated, form the major aquifers in the western portion of the valley, while the extensive clay layers separating and overlying them act to confine the ground water present within the aquifers. These clay layers or aquicludes are responsible for the confined ground water conditions in the western part of Livermore Valley. Within the upper 300 to 400 feet of alluvium, the aquifers have been identified as the upper, second, third, and fourth aquifers (shown on Plate 4) according to their respective locations below the ground surface. Four aquifers and aquicludes have been traced in the Pleasanton subbasin but, because of an insufficient number of deep well logs, only three have been traced in the north portion of the Santa Rita subbasin. Other aquifers exist at greater depths, particularly along the southwest portion of the valley, but they cannot be traced far because of the lack of well logs.

With the exception of the upper aquiclude and upper aquifer, which are continuous over nearly the entire western half of the valley, deeper aquifers and aquicludes extend as unbroken layers only between the faults that cut the alluvium. They cannot be traced across these faults at the same elevation, apparently because they have been offset or eroded as a result of fault movement.

The upper aquiclude caps nearly the entire western portion of Livermore Valley. It represents the uppermost confining clay layer and together with the soil zone, ranges in thickness up to 70 feet, as shown on Plate 9A. The contours on Plate 9A describe elongated troughs and ridges that probably reflect the location of old stream channels. The southern portion of the Pleasanton fault (the boundary between the Pleasanton and Santa Rita subbasins) is revealed by the contours which parallel it and show that the upper aquiclude thickens from about 25 feet on the west side to about 50 feet on the east side of the fault. Movement along the fault may have produced a scarp that controlled drainage and deposition during the period of aquiclude formation.

The upper aquifer extends over the northern part of the Santa Rita subbasin, and the entire Pleasanton and San Ramon subbasins. It lies directly beneath the upper aquiclude, but is exposed as the uppermost portion of the alluvium in the southern part of the Santa Rita subbasin.

The upper aquifer consists principally of a permeable mixture of sand and gravel and ranges in thickness from about 25 feet in the subbasins west of the Pleasanton fault, to a maximum recorded thickness of 105 feet in the Santa Rita subbasin (on well log 3S/1E-10N1). It thins somewhat to the east and west from the above maximum, but remains the thickest single aquifer in Livermore Valley. The second aquiclude lies beneath the upper aquifer, in the north portion of the Santa Rita and Pleasanton subbasins. This fine-grained layer has a fairly consistent thickness of 20 feet and greatly restricts ground water in the upper aquifer from moving downward into the second aquifer. In the Santa Rita subbasin, the second aquiclude extends farther south than the upper aquiclude, which makes the area of confined ground water larger for the second aquifer.

The second and third aquifers in the alluvium dip westward in the Santa Rita subbasin and northward in the Pleasanton subbasin (Plate 4). This dip reflects the general direction of stream flow during deposition of the aquifers and confirms the similar direction of flow, based on the variation in thickness of aquifers, that is shown by the arrows on Plate 7 and 8.

The nature of the alluvium in each subbasin will be discussed more fully in Chapter VI, in relation to the occurrence and movement of ground water.

CHAPTER IV. GEOLOGIC HISTORY

The geologic history of the oldest rocks in the Alameda Creek watershed dates back to the Jurassic period, some 160 million years ago. However, only the last 12 million years since the early Pliocene epoch encompassed the complete structural and depositional evolution that produced the sediments that now comprise the Livermore and Sunol Valley ground water basins. This younger sequence of sediments is the most important to this study; consequently, only the geologic history of the region since early Pliocene time will be discussed.

Pliocene Time

In early Pliocene time, the entire Bay region appeared quite different than it does today. An elongated mountainous land mass existed where San Francisco Bay now lies, flanked on the east and west by structural troughs. The western trough was occupied by the Merced seaway and the eastern, Orinda trough was a lowland undergoing continental deposition. The Orinda trough was cut off from the Merced sea and was continually receiving alluvial sediments derived by erosion from both the elongated mountain mass on the west and the ancestral Diablo Range on the east. These sediments were deposited in flood plains and shallow lakes and are today exposed as the Orinda Formation.

Erosion of the mountains and the deposition of Orinda :diments continued during middle Pliocene time until the entire :gion was reduced to low relief.

During late middle Pliocene time great crustal disturb- ıces caused the entire Coast Range to be uplifted and compressed ı a northeast-southwest direction. The rocks of the region were aulted and folded while the flat-lying Orinda sediments were olded and eroded into a series of parallel-trending ridges and arrow valleys.

Toward the end of this period of uplift and erosion, ithin the area now occupied by the two ground water basins, the ivermore depression gradually developed as a downwarp between ;wo zones of weakness, the Calaveras fault on the west and the Riggs Canyon-Greenville fault on the east. Streams draining primarily from the southwest eroded the Cretaceous and Jurassic rocks exposed there and deposited these erosion products on great outwash plains and in lakes within the Livermore depression. Exposures of these deposits are today called the Livermore Formation.

Pleistocene Time

The deposition of Livermore sediments and erosion of the highlands continued well into the Pleistocene time until the region was once again reduced to a rolling lowland named by Crittenden the Oak Ridge erosion surface.[6]

During mid-Pleistocene time, renewed crustal activity occurred. The Livermore depression again subsided and the Livermore sediments were slightly folded, faulted and together with the Oak Ridge surface were gently tilted to the north. The larger faults of the region were reactivated and the lesser faults were newly formed. Activity along the Calaveras fault, and the Sinbad fault west of it, resulted in subsidence of the block between them and the development of Sunol Valley.

The landscape of the Bay region following the mid-Pleistocene uplift appeared much as it does today. The depressions now occupied by San Francisco Bay and the ancestral Livermore and Sunol Valleys were present with mountains surrounding them.

Uplift and northward tilting of the Oak Ridge surface gradually created a strong stream system draining into the Livermore depression and newly formed Sunol depression from the south, and active stream cutting and deposition began anew. These streams gradually cut broad valleys in the Oak Ridge surface and deposited the erosion products as Quaternary alluvium upon the depressed portions of the Livermore Formation.

Streams draining the highlands south of Livermore Valley probably flowed north to the ancestral Sacramento River, while the streams draining the ancestral Sunol highland emptied, as they do today, into the Bay depression. A very early route to the Bay depression may have been south of the present outlet, for a broad valley exists in the long profile of the ridges separating Sunol Valley from the Bay depression. This ancient valley is clearly visible from the south end of the Bay, since its axis lies along the Mission Pass road. At some later time, the present route was established through Niles Canyon and was maintained during the mid-Pleistocene uplift by a vigorous Alameda Creek.

In late-Pleistocene time, slight crustal compression caused gentle uplift of the region and rejuvenation of the established north-flowing streams. The amount of stream erosion that has occurred since this uplift can be seen by the V-shaped canyons that now mark the streams draining the Livermore highlands. Remnants of the older broad-valley stage can be seen today in the Cretaceous and Jurassic rocks as benches above the V-shaped canyons. Remnants of the much older Oak Ridge surface can also be seen today as the concordant summits of ridges in the Sunol and Livermore highland.

Recent Time

From the late-Pleistocene disturbance until the present time, stream erosion of the highland and deposition of the erosion products in valley depressions has continued, resulting in the water-bearing Quaternary alluvium now preserved in Livermore, Sunol, Vallecitos, and La Costa Valleys. Both Vallecitos and La Costa Valleys are very recent developments in the geologic history of the area, representing little more than a shallow veneer of alluvium overlying the Livermore Formation.

Early in the period of alluvial deposition, large streams entering the Livermore depression from the south crossed Livermore Valley from east to west primarily along the southern border. These streams joined at the northwest corner of the valley and flowed out through San Ramon Valley to empty into the ancestral Sacramento River in the area now occupied by Suisun Bay. The ancient outlet through San Ramon Valley was probably largely controlled by movement along faults associated with the Calaveras system. The southern streams were able to deposit coarse alluvium because of their large drainage area and partly because the Livermore Formation gave them a ready-made source of gravel. These streams merely cleaned up gravel eroded from the Livermore outdrops by wearing away the weathered, less resistant pebbles and washing away the interstitial fines. Coarse alluvium, up to boulder size, was gradually deposited close to the area where the old streams entered the flat valley and progressively finer fractions were deposited further down gradient to the west and north.

During periods when the northwest outlet of the valley was open and the stream gradient steep, the southern streams, particularly ancestral Arroyo del Valle, were able to deposit gravel over nearly the entire floor of the valley. Great sheets of clean gravel thus gradually accumulated as the streams worked their way back and forth over the valley floor.

During periods when the northwest outlet of the valley was blocked, the carrying capacity of the streams crossing the valley was reduced and swamps and lakes formed in the western portion. Gravel could no longer be carried as far as before and great continuous sheets of silt and clay were deposited in and near the lakes on top of the previously deposited gravel layers.

At least four thick clay layers separated by extensive gravel beds are known to be present in the western portion of the valley, indicating four periods during which the outlet was blocked and a lake was present in Livermore Valley.

The sharp contact between these layers of gravel and clay indicates that the environmental change from outwash plain to lake was rapid. Movement along the Calaveras fault system probably caused uplift or landslides that blocked the northern outlet.

Sometime during the very recent past, the outlet from Livermore Valley abandoned its ancient course to the north and established its present southwest outlet along Arroyo de la Laguna and through Niles Canyon to South San Francisco Bay. This change probably took place as a result of regional upwarping along the northern outlet in the San Ramon area, and as a result of stream capture by a tributary to Alameda Creek along the weak Calaveras fault zone.

The present stream outlet from Livermore Valley was probably established during a time when the uppermost gravel layer, called the upper aquifer, was being deposited. Evidence for this is shown by the thickness of gravel present in the upper 100 feet of alluvium, as shown on Plate 6. The gravel is considerably thicker in the southwest corner of the valley, extending along the stream course of Arroyo de la Laguna, than it is in the San Ramon subbasin. The course of the stream that deposited the upper aquifer gravel is shown by the areas of greatest gravel thickness.

Accumulation of the upper aquifer gravel came to an end suddenly by the formation of a lake. Up to 60 feet of clay was deposited in this lake which today forms the clay cap called the upper aquiclude. A small remnant of this lake, surrounded by extensive swamp conditions, existed in the area northwest of Pleasanton until the early 1900's, when it was drained by man.

The formation of the recent lake may have been caused by continued subsidence of the Livermore depression, or by blockage of the outlet along Arroyo de la Laguna resulting from landslides or vertical movement along the Calaveras fault zone. The presence of an ancient landslide just west of the narrow canyon of Arroyo de la Laguna is suggested by the irregular, bumpy terrain underlain by what has been mapped by Hall[9/] as the Livermore Formation.

Crustal movements that have gone on in California for so long are still active in the region. Earth tremors are associated with both the Calaveras and Riggs Canyon-Greenville faults, and the Quaternary alluvium has been cut by the Livermore, Pleasanton, Parks, and Verona faults. Livermore Valley is probably continuing to subside tectonically, and alluvium is continually being carried in by streams to fill it.

CHAPTER V. FAULTS AFFECTING GROUND WATER MOVEMENT

Within the Livermore Valley and Sunol Valley ground water basins, faults are the major structural features known to have marked affect on the movement of ground water. Faults in this region tend to act as barriers to the lateral movement of ground water with the result that ground water levels stand higher on the up-gradient side. Three largely concealed faults beneath Livermore Valley, the Livermore, Pleasanton, and Parks faults, were first recognized because of the pronounced difference in water levels observed in wells on either side of them.

In this appendix only those faults that are known or suspected of controlling the movement of ground water are discussed. These include the Livermore, Pleasanton, Parks, Verona, and Calaveras faults. Several other faults, shown on Plate 3, have been mapped within the boundaries of the two ground water basins but their relation to ground water movement is not known. It should be remembered, however, that any fault that cuts the water-bearing sediments in this region may act as a barrier to the movement of ground water.

Faults that are known to act as barriers to the lateral movement of ground water in this region probably do so in one or more of the following ways:

1. Nonwater-bearing rock may be brought in contact with water-bearing sediments.

2. Aquifers within the water-bearing sediments may be offset and brought in contact with less permeable portions of these sediments.

3. Fine-grained fault gouge may be present along the fault plane, creating in effect a membrane of low permeability, through which ground water has difficulty moving.

Livermore Fault

The Livermore fault trends in a northwest-southeast direction just west of the town of Livermore and constitutes the boundary dividing the Livermore and Santa Rita subbasins. The presence of the Livermore fault was first recognized because well water levels stood as much as 100 feet higher on the east than on the west side of the fault.

The only known exposure of the fault occurs in a landslide scar on the east side of Oak Knoll (a low hill composed of the Livermore Formation) just west of the stream bed of Arroyo Mocho. Active undercutting by this stream tends to maintain fresh exposures of the fault by causing small additional slides. At least a portion of the fault became clearly exposed in this manner at the southeast end of the main slide scar in 1957. Clay gouge along the fault plane and truncated beds of gravel in the Livermore Formation were clearly visible. In addition, the main slide scar shows many slickensided surfaces that represent subordinate planes of movement parallel to the main fault.

The strike of the Livermore fault can be rather carefully established as N.45°W. since it must lie on the east side of

Oak Knoll and trend to the northwest between wells 3S/2E-7C1 and 3S/1E-12H1. These wells are only 1/4 mile apart, but in 1961 had a water level differential of about 80 feet.

Water levels, well production, and well logs indicate that a west branch of the Livermore fault exists just west of Oak Knoll and the similar low hill to the northwest of it. These two hills probably represent a sliver of the Livermore Formation brought up between the Livermore fault and its west branch.

The fault definitely acts as a barrier to the normal westward movement of ground water, but not with equal effectiveness along all portions of its length. The presence of the fault sliver, exposed as hilly outcrops of the Livermore Formation, makes this portion of the fault zone most effective as a barrier. The fault trace just north of the point at which the west branch joins the main fault is least effective as a barrier, and the portion south of Oak Knoll is of medium effectiveness.

Pleasanton Fault

The Pleasanton fault trends in a northwest-southeast direction, just east of the town of Pleasanton, and constitutes the dividing boundary between the Santa Rita and Pleasanton subbasins, and the Parks and San Ramon subbasins. Like the Livermore fault, the Pleasanton fault was first located as a barrier because ground water levels often stood as much as 50 feet higher on the east side. The fault is actually in two parts, a main west portion and a discontinuous east branch.

The northern portion of both the main fault and the east branch are visible on aerial photographs taken in 1940 by the

Commodity Stabilization Service, U. S. D. A. and appear most clearly on photo No. BUT-341-105. Both fault traces appear on the above photograph as dark lines against a slightly lighter-toned background that perhaps result from a slight difference in the moisture content of the soil. The portions of the two fault traces that are visible on aerial photographs are shown by the solid lines on Plate 3, while the portions that show no surface expression are shown by dotted lines. Topographic evidence of the main fault include small creek channels that parallel the trace, including a 1,200 foot stretch of Alamo Creek, and aligned ravines, particularly where the main fault crosses the Orinda Formation between South San Ramon and Alamo Creeks.

The southern portion of the Pleasanton fault, while showing no surface expression, was located by the substantial difference in water levels observed in the abundant wells located on either side of it.

The southern portion of the fault is a barrier, apparently because aquifers were offset and positioned opposite clay members as shown on Section C-C' on Plate 4. Only the upper aquifer appears still to be continuous across the fault. This may allow ground water to move westward across the fault more freely at shallow depths.

Parks Fault

The Parks fault trends in an east-west direction, but is curved in its western portion to assume a northeast-southwest orientation. The eastern portion of the fault constitutes the dividing boundary between the Santa Rita and Parks subbasins and the western portion the dividing boundary between the Pleasanton and San Ramon subbasins.

There is no surface evidence of this fault, but a marked water level differential from north to south of about 20 feet is present along its entire length. The quality of ground water also changes at or very near the fault from a sodium bicarbonate-chloride type on the north side to a magnesium bicarbonate type on the south side. The water level differential and quality change described above show that the fault acts as a barrier to the southerly movement of ground water.

The barrier effect along the western portion of the Parks fault seems to be the result of actual offset of the alluvium, as illustrated on Section D-D', Plate 4. However, the barrier effect along the eastern portion is apparently more complex as we shall see.

The Parks subbasin is underlain by the Orinda Formation at shallow depth while just south of the fault, in the Santa Rita subbasin, alluvium is very thick; consequently, a buried hill front exists along the fault trace that probably represents a fault scarp or fault line scarp.

The observed ground water differential of 20 feet, that exists from north to south across the Parks fault, is partly the result of a ground water cascade. This cascade is created as perched ground water in the thin alluvium in the Parks subbasin moves laterally south on top of the shelf of Orinda Formation, across the fault zone, and then downward into the upper aquifer, in the Santa Rita subbasin. This is not the only way in which the fault affects ground water, as indicated by the water levels in wells located in the eastern portion of the Parks subbasin. In that area, the ground water gradient is westward, parallel to the fault, suggesting that little movement occurs across the fault zone. Consequently, while the buried hill front probably controls the way in which ground water moves from the Parks subbasin to the Santa Rita subbasin along this entire boundary the fault must be an actual barrier to ground water movement along the eastern portion of the above boundary.

Verona Fault

The Verona fault trends about N70°W and is located near the boundary between the Livermore and Sunol Valley ground water basins. The western end of the fault cuts the alluvium in the canyon of Arroyo de la Laguna and then joins the Calaveras fault.

Hall [9] suggests that the Verona fault is an important branch of the Calaveras fault, and that recent vertical movement had displaced the Livermore Formation as much as 450 feet.

The west end of the fault, as mapped by Hall, passes between wells 3S/1E-29N1 and 29M2. In May 1961, there was a 15 foot difference in the elevation of the water surface in these two wells, with the south well having the higher level. These and other well water levels suggest that the Verona fault acts as a ground water barrier where it crosses the alluvium in the narrow canyon of Arroyo de la Laguna. The probable structural condition across this portion of the Verona fault is illustrated on section D-D', Plate 4.

Since the Verona fault appears to act as a barrier to the movement of ground water in the alluvium and is known to have displaced the Livermore Formation, it follows that the fault probably acts as a ground water barrier along its entire length. No wells are available to substantiate this suggestion.

Calaveras Fault

The Calaveras fault lies along the base of Pleasanton Ridge and closely approximates the western boundary of Livermore Valley. This fault is one of the largest in California, extending to the north beyond Suisun Bay and to the south into the Gilroy-Hollister area. The Calaveras fault is primarily a right-lateral, strike-slip fault with a vertical component responsible for the upward movement on the west side. Vickery[19] states that the relative horizontal movement along the fault has been 12 to 13 miles; however, using Vickery's criteria, Hall[9] suggests relative horizontal movement of 3 to 4 miles. Exposures of the fault, as stated by the above authors, indicate that the prevailing dip of the fault plane is to the west; thus, the vertical component of fault movement is reversed.

The Calaveras is such a large fault that it probably occupies a relatively wide zone rather than a distinct single trace. The location of the fault shown on Plate 3, very near the western edge of Livermore Valley, probably represents the trace of only the most recent movement; and other, older traces may lie hidden beneath the valley alluvium somewhat further east. While no direct evidence exists, the consistent width of San Ramon Valley suggests that it may be fault controlled.

A concealed branch of the Calaveras fault may exist just west of the Camp Parks sewage ponds. The presence of this fault is suggested by slightly higher water levels in wells on the west side and an abrupt change in the quality of ground water from a calcium-sodium bicarbonate type on the west to a sodium bicarbonate-chloride type on the east.

No actual evidence exists that the mapped trace of the Calaveras fault constitutes a barrier to the movement of ground water across it. However, the fault zone has produced a barrier in the presence of the uplifted block of nonwater-bearing rock to the west. Relatively recent vertical movement along the fault trace on the eastern edge of Sunol Valley suggests that it may constitute a barrier to the movement of ground water into Sunol Valley from the Sunol upland.

CHAPTER VI. OCCURRENCE AND MOVEMENT OF GROUND WATER

A ground water basin consists of an area underlain by water-bearing material and includes the entire volume of that material. Ground water basins are often subdivided into subbasins along barriers that restrict the flow of ground water.

The Livermore Valley and Sunol Valley ground water basins have been divided into eight subbasins, as shown on Plate 2, on the basis of ground water barriers or formational contacts. The upland areas in each basin are not considered subbasins because no barrier to the flow of ground water exists at the contact with the valley areas. However, because the occurrence and movement of ground water beneath the uplands is different than beneath the valleys, the uplands will be described as a separate unit. The occurrence and movement of ground water will be described separately for each subbasin because the compartmenting effect of the barriers allows ground water in each subbasin to act to some degree in an independent manner.

Livermore Valley Ground Water Basin

The Livermore Valley ground water basin includes the areas occupied by both Livermore Valley and the Livermore upland. These areas are underlain respectively by Quaternary alluvium and the Livermore Formation, the only water-bearing formations within the Livermore drainage unit. The alluvium is by far the most permeable and therefore the most important unit in the basin, since virtually all wells draw their supply from it. The alluvium of the valley floor and the underlying Livermore Formation is divided along three faults into the Livermore, Parks, Santa Rita, San Ramon, and Pleasanton subbasins.

The northern boundary of the basin is the limit of the alluvium except the northwestern boundary of the San Ramon subbasin where the surface water divide has been used. The narrow strips of alluvium along both Alamo and Tassajara Creeks have not been included as part of the Livermore Valley ground water basin because the alluvium is of insignificant thickness and is underlain by nonwater-bearing rocks.

The surface water divide separating the Livermore upland and Sunol upland has been arbitrarily chosen as the division separating the two ground water basins. The western extension of this divide crosses Arroyo de la Laguna at a point approximately one-quarter of a mile south of Hacienda Road. This particular locality was chosen because the alluvial filled channel of Arroyo de la Laguna is narrow at this point and bordered on each side by exposures of nonwater-bearing rocks.

The ground water basin is limited at depth to the base of the Livermore Formation. Ground water in the exposed Livermore Formation moves generally northward and under the alluvium of Livermore Valley. Upward leakage may supply some recharge to the alluvium.

Ground water in the Quaternary alluvium moves generally from the northern and southern portions of the valley toward the center, and from east to west. Ground water levels are always lowest in the Pleasanton subbasin, and there has been no subsurface outflow from the basin since 1945, because of heavy pumping draft.

Livermore Upland

The Livermore upland encompasses all of the exposures of the Livermore Formation within the ground water basin. Small exposures occur on the east and west sides and within Livermore Valley. By far the largest and most important exposures occur south of the valley, and the following discussion will refer primarily to that portion of the upland. In all exposures, the Livermore Formation appears to be clay-rich and of low permeability. This is generally substantiated at depth by the low yield of wells known to penetrate the formation, and by the low gravel content as described on the logs of many of these same wells.

Wells in the Livermore upland produce ground water in quantities sufficient only for low demand domestic and stock watering purposes. These wells are so sparsely located that the actual configuration of the water table and hence the direction of ground water movement cannot be determined. The following discussion of the movement of ground water in the Livermore Formation represents the most logical picture consistent with available evidence.

Recharge of the Livermore Formation is accomplished primarily by percolation of rain falling on the Livermore upland. A portion of this rainfall penetrates the soil cover and moves as ground water both down-slope toward topographically low areas and into permeable beds that have been exposed to entrance by erosion. The prevailing dip of these beds tends to convey this ground water northward and into the Livermore Formation beneath Livermore Valley.

Clay layers that may be extensive in the formation, probably cause the ground water to become confined as it moves northward. Several wells that penetrate the Livermore Formation in the upland along Sycamore Road and Alisal Street, southwest of Pleasanton, were flowing in past years, showing that ground water is definitely confined at least locally.

All the wells along the northern margin of the Livermore upland have water levels often standing higher than wells penetrating only alluvium beneath the valley. Therefore, a pressure gradient often exists from the Livermore Formation to the alluvium along the southern margin of the valley and some ground water probably moves laterally and upward into the alluvium along this margin. Compared to the quantity of recharge to the alluvium from surface sources, the underflow contribution from the Livermore upland is small. However, in spite of its low permeability, the large area and considerable thickness of the formation beneath the upland suggests that it holds a large volume of ground water in storage.

Livermore Subbasin

The permeability and thickness of the water-bearing deposits in the Livermore subbasin are quite different in each of three areas. Because these differences markedly affect the occurrence and movement of ground water in each area, the three areas have been separated for descriptive purposes and named the northern unit, southeastern unit, and southwestern unit. The area included in each unit is outlined on Plate 5 and each unit has been designated by letters as follows: A-northern unit, B-southeastern unit, C-southwestern unit. The difference between units is as follows. In the northern unit, the alluvium is of low permeability, does not exceed 100 feet in thickness, and is underlain by nonwater-bearing formations. In the southeastern unit, the alluvium is moderately permeable, does not exceed 200 feet in thickness, and is underlain by the Livermore Formation. In the southwestern unit, the alluvium is highly permeable, exceeds 200 feet in thickness, and is underlain by the Livermore Formation.

In general, then, the productivity, and therefore the importance, of the three units in the Livermore subbasin increases from north to south and from east to west. This is also the general direction in which ground water moves in the subbasin.

Northern Unit. The northern unit is the least important ground water producing area in the subbasin because only the alluvium is water-bearing and it is thin, fine-grained, and contains poor quality water.

The alluvium does not exceed 100 feet in thickness, is underlain by both the Orinda Formation and Miocene rocks (along the northeastern edge), and is described on well logs as sandy clay, clay and silt, with occasional small-sized gravel layers. In addition, the recent soil survey[17/] reports that the portion of the unit north of Altamont Creek is capped by clay over 60 inches thick and that the remaining portion of the unit is underlain by soil types containing extensive clay pan of low permeability.

Ground water is probably confined beneath the clay cap north of Altamont Creek but is probably only semi-confined in the remaining portion of the unit.

The quality of ground water in the northern unit is generally poor. The total dissolved solids content averages 2,150 parts per million and the ground water is of a sodium chloride-sulfate type, high in Boron[2].

The soil over much of the northern unit is rich in salts. As early as 1911, large areas of soil high in sodium sulfate and sodium chloride were mapped.[20] The highest concentration of these salts occurs in soils near Altamont Creek northwest of its junction with Arroyo Las Positas. This area coincides with a low spot in the topography just northeast of the hilly outcrops of both Orinda and Livermore sediments.

The high ground water levels, salt-rich soil, and poor ground water quality all suggest that ground water in most of the northern unit does not readily move into the southeastern unit. This is due to the fine-grained nature of the alluvium and to exposed and thinly-buried hills of Orinda and Livermore sediments which restrict such movement. Instead, most of the small quantity of ground water entering the unit probably escapes by evapotranspiration (resulting in the salt-rich soil) and by periods of effluent seepage to Altamont Creek.

Ground water recharge in the northern unit occurs primarily from small streams draining the surrounding hills. However, only small portions of the flow in these streams actually infiltrates, because of the fine-textured soils underlying their channels.

Altamont Creek, the largest stream in the unit, seems to be relatively unimportant as a source of recharge primarily because of the low permeability of the alluvium beneath its channel. The infiltration along the entire 5.2 mile stretch of Altamont Creek channel above its junction with Arroyo Las Positas is estimated to be 0.6 acre feet per day.[3/]

Southeastern Unit. The southeastern unit is the second most important ground water producing area in the subbasin. Most of the water wells in this unit are relatively deep, extending to depths up to 700 feet; consequently, much of their supply is drawn from the Livermore Formation underlying the alluvium.

Water levels in wells known to tap the Livermore Formation are quite commonly erratic in relation to each other. Wells of this type only a few hundred feet apart often have static water levels many feet different in elevation. This characteristic shows that ground water is at least partially confined in many individual aquifers having limited interconnection. In spite of this evidence of partial confinement, ground water in the Livermore Formation in both the southeastern and southwestern units should be treated during the hydrologic studies as essentially unconfined, because the existance of discontinuous aquifers and the lack of extensive aquicludes in the Livermore Formation do not supply the conditions necessary for long-term confinement. Short periods of stress, such as heavy pumping or active recharge, produce local evidence of confinement in the form of water level differentials, but this evidence gradually disappears as the stress is relieved.

Ground water recharge to the alluvium in the southeastern unit occurs primarily by infiltration from Arroyo Seco. Ground water in the alluvium, in turn, supplies recharge to the underlying Livermore Formation both in the southeastern and southwestern units. This is most likely accomplished in the following manner. The consistent known dip of the Livermore Formation must persist beneath the alluvium so that eroded ends of permeable beds are in contact with permeable portions of the overlying alluvium. In such contact areas, ground water has an opportunity to move downward to recharge these individual beds in the Livermore Formation. The necessary potential for such downward recharge from the alluvium is always present as shown by water levels that always stand higher in shallow wells than in deeper ones. Recharge to deep aquifers in the Livermore Formation also takes place by slow movement down dip from the hills south of the valley.

Southwestern Unit. The southwestern unit is the most important ground water producing area in the subbasin because it is the most permeable. Plate 5 shows that aquifers comprise up to 60 percent of the upper 300 feet of sediments. The high percentage of aquifer material and the shape of the percentage contours suggest that ancestral Arroyo Mocho has cut a canyon in the Livermore Formation at least 300 feet deep that is now backfilled with permeable alluvium. The northern wall of this buried canyon probably lies along the northern boundary of the unit.

Some recharge occurs from the southeastern unit by underflow. A marked water level differential (nearly 100 feet) across the boundary between the two units has been observed in wells. This differential suggests that ground water moves slowly from the Livermore Formation in the southeastern unit into the more permeable southwestern unit.

Recharge in the southwestern unit occurs primarily along the channel of Arroyo Mocho which is the second most important recharge stream in the valley. Arroyo Seco is of secondary importance and Arroyo Las Positas is the least important as a source of recharge. Water in each of these three streams has particular chemical characteristics, reflected in the quality of ground water near their courses, that roughly show the area influenced by recharge from each stream.

Ground water in the southwestern unit moves westerly through the Livermore fault to recharge confined aquifers in the Santa Rita subbasin. However, the fault definitely acts as a barrier, causing a maximum water level differential of up to 90 feet from the east to the west side. The water level differential is much less in shallow wells, suggesting that the fault presents much less of a barrier to ground water moving through shallow aquifers.

Parks Subbasin

Within the Parks subbasin, water wells are of low yield, indicating sediments of low permeability. Well logs describe these sediments as sandy-clay with occasional sand beds.

Several test holes drilled in 1963 on the Camp Parks property, in the northwest part of the Parks subbasin, indicate that the alluvium is less than 100 feet thick and is underlain by the nonwater-bearing Orinda Formation. The alluvium penetrated was fine-grained and essentially dry.

The only water well near the drilled area is well No. 2S/1E-33M1 located at the mouth of Tassajara Creek. This well apparently receives underflow from the creek. Since no other water wells are present, the test hole evidence strongly suggests that the northwest quarter of the subbasin is unproductive for ground water.

The sodium bicarbonate-chloride type ground water produced from wells of low yield in the east portion of the Parks subbasin apparently comes from the foothills to the north, and is in striking contrast to the calcium-magnesium bicarbonate type ground water pumped from wells of high yield south of the Parks fault in the Santa Rita subbasin. Water levels in wells north of the fault stand as much as 40 feet higher than in wells of equal depth just to the south. These facts again point out the difference between the occurrence of ground water in the Parks and Santa Rita subbasins and the degree of isolation between them apparently caused by the Parks fault.

Ground water in the Parks subbasin moves principally westward parallel to the Parks fault in the narrow eastern part and southward across or through the Parks fault in the wider western part of the subbasin. Thus, the eastern portion of the fault apparently presents more of a barrier to the southern movement of ground water than the western portion.

A consistent water level gradient to the south shows that a small quantity of ground water moves south through the fault and recharges the upper aquifer in the Santa Rita subbasin. The deeper confined aquifers apparently receive no ground water from the sediments in the Parks subbasin, since the gradient of the deeper aquifer pressure surface in the Santa Rita subbasin does not increase near the Parks fault. Moreover, the mineral characteristics of ground water in the deeper aquifers are much different from those in ground water in the Parks subbasin.

Santa Rita Subbasin.

The Santa Rita subbasin is the second most productive area in the basin. Wells reach a depth of 755 feet and tap both free and confined ground water in very permeable gravel aquifers. The upper aquiclude caps the northern portion of the subbasin and the upper, second, and third aquifers are present beneath.

The upper aquiclude is thick and of low permeability, thereby restricting the movement of surface water seeping through it into the underlying upper aquifer. However, this restriction becomes progressively less effective as the aquiclude becomes both thinner and more permeable to the south and east (Plate 9A).

Within the upper aquifer, ground water is usually unconfined, since air fills the voids in the gravel between the water table and the upper aquiclude.

Aquicludes restrict the movement of ground water between aquifers thus making each aquifer hydrologically independent. This hydrologic independence is shown by water levels in wells perforated in only one aquifer which are strikingly different in elevation from those in nearby wells perforated in a different aquifer. In May 1961, three distinct sets of water levels were found, each of which corresponded to wells perforated in one of the three main aquifers. These three sets of water levels were up to 25 feet apart, as shown on sections C-C' and D-D', Plate 4. The deeper aquifers had the lower levels, a condition which often is characteristic of active ground water basins, owing to deep pumping and surface recharge.

In the Santa Rita subbasin, all the aquicludes in the alluvium become gradually more permeable, thinner, and more difficult to distinguish on well logs toward the southeast. This tendency is shown best by the upper aquiclude which grades to the southeast from a clay to a sandy-silt while becoming progressively thinner (as shown by the contours on Plate 9A), until it merges with the soil zone south of the Southern Pacific railroad. The second aquiclude becomes indistinguishable in well logs as a recognizable layer somewhat further south. The portion of the subbasin south of this above limit is the major forebay for the confined aquifers in the north portion of the Santa Rita subbasin. Ground water recharged in the forebay moves north and west toward areas of depletion, becoming confined under pressure beneath the progressively thickening aquicludes.

During the dry season, a large proportion of the total amount of recharge to the upper aquifer occurs by subsurface inflow of ground water through the Livermore fault. Evidence for this is shown by the shape of contours drawn for the water levels in wells tapping the upper aquifer. Just west of the Livermore fault, the contours slope to the west and lie parallel to the fault.

In the north portion of the subbasin, both the shallow unconfined and deep confined ground water moves westerly toward and through the Pleasanton fault into the gravel aquifers of the Pleasanton subbasin. Both the main Pleasanton fault and the east branch act as partial barriers to the westward moving ground water so that the water levels in the wells east of the faults are always higher than those to the west.

The most rapid westward movement of confined ground water through the Pleasanton fault appears to occur in the central portion just north of the branch point, which indicates that the fault is more permeable at depth. However, upper aquifer ground water appears to move most rapidly through the southern portion of the fault south of the branch point. Apparently this is the most permeable area in the shallow portion of the fault. The total drop in water levels in deep wells westward across the fault was 25 feet in May 1961.

The Livermore Formation lies at relatively shallow depth beneath the alluvium both along the southern margin and in the southeastern quarter of the subbasin. This is apparently the result of the meanderings of Arroyo del Valle in past time. As the stream slowly moved across the valley floor, mostly south of its present channel, it planed off exposed portions of the Livermore Formation to form a flat bench along the foot of the hill front. This buried bench, now covered by a thin veneer of alluvial gravel, extends from the hill front to the center of section 15, T3S/R1E, where in 1962, it was exposed in a large, deep Kaiser gravel pit. Near the north side of this pit, this erosion surface was observed to steepen, forming a steep buried hill front. These observations show that all water wells located near the north edge of the hills must penetrate and draw most of their ground water supply from the Livermore Formation, even though they appear from the geologic map to be entirely in alluvium.

Several exposures of the Livermore Formation were observed in gravel pits and in the present bed of Arroyo del Valle within a two mile distance east of Pleasanton. The more easterly of these exposures shows the Livermore Formation to be composed of predominently reddish, clayey gravel and thick beds of silty clay, all striking northwest and dipping about 35 degrees to the northeast. Because of the lenticular nature of the sedimentary layers in the Livermore Formation and the fact that they are dipping, it has not been found possible to correlate individual aquifers between well logs. As described above, these dipping beds have been truncated by the past action of surface streams and then covered by a layer of permeable alluvium, consequently, surface water can easily recharge the more permeable beds in the Livermore Formation. Ground water trapped between relatively impermeable clay beds in this way may slowly recharge deep aquifers under the valley further north.

Arroyo del Valle, when flowing during the rainy months, recharges the deeper aquifers along its upper reaches until it encounters the truncated beds in the Livermore Formation sparsely exposed in its channel at the north edge of section 23 (T3S/R1E). From here to a point about one mile further downstream, infiltration from the channel bottom is greatly reduced except where the creek encounters occasional permeable beds in the Livermore Formation. Most of the water that infiltrates in

The water levels in shallow wells throughout the subbasin describe a pressure surface sloping to the south, in the direction of ground water movement.

Correlation of electric logs obtained from the nine wells and test holes drilled for water supply for San Ramon Village reveals that alluvium occurs in the north portion of the San Ramon subbasin to depths as great as 700 feet. Correlation of individual zones between the logs of wells 26G1, 26H1, and 25E1 (all within T2S/R1W) shows that these layers are essentially horizontal, with only slight dip to the west. Correlation of electric logs between wells in a general north-south direction was less positive. However, these logs do suggest that the alluvium dips gently to the south and secondly, that the alluvium also becomes thicker in that direction.

All the deep wells are located in the portion of the subbasin north of Highway 50; consequently, the nature of the sediments at depths greater than 255 feet in the southern portion of the San Ramon subbasin is not known. Within this area, however, a test hole drilled by the Department of Water Resources, and completed as Well No. 3S/1E-7E2, explored to a depth of 183 feet and encountered only the gravelly upper aquifer. The interval beneath the upper aquifer was composed of sandy clay without any coarser-grained sediments. A test well drilled to 255 feet, 1,000 feet west of the above well, and designated

3S/1E-7M1, produced only 20 gallons per minute. These two test wells reveal a lack of aquifers between the base of the upper aquifer and a depth of 255 feet just south of the Parks sewage disposal ponds, that may indicate the presence of a buried hill or shelf of essentially nonwater-bearing sediments.

The apparent southern dip of the aquifers at depth in the San Ramon subbasin is surprising in light of the past history of the area. These aquifers must have been deposited by the ancient streams that drained to the north through San Ramon Valley and into Suisun Bay. Consequently, their original dip must have been to the north. The present southern dip of these deeply buried aquifers may have resulted during upwarping of the region to the north and depression of Livermore Valley.

Ground water in the upper aquifer in the San Ramon subbasin moves gradually south through the Parks fault and into the upper aquifer in the Pleasanton subbasin. The Parks fault restricts this southern movement, as evidenced by the water level differential of up to 12 feet that is present across it. The fault acts as a barrier to the movement of ground water in deeper aquifers also, and the degree of restriction probably increases in depth.

No information has been obtained concerning water levels in the deep wells drilled for San Ramon Village in 1961, so that the direction of ground water movement in deep aquifers is not known. However, the historic ground water gradient has been to the south into the Pleasanton and Santa Rita subbasins.

Pleasanton Subbasin

The Pleasanton subbasin is the most productive portion of the ground water basin. Extensive use of ground water began in this subbasin as early as 1898, and production and exportation of large quantities of water continued until the end of World War II. Ground water levels have always been at a lower elevation in this subbasin than elsewhere in the basin, a condition that is maintained both by subsurface outflow when water levels are high, and by ground water extraction.

The upper 350 feet of alluvium in the Pleasanton subbasin is made up of alternating layers consisting of four gravel aquifers and four confining aquicludes overlying them. Productive gravel aquifers exist at greater depth, but lack of well logs extending deeper than the fourth aquifer make it impossible to trace them very far. These deeper aquifers may be part of the Livermore Formation.

The upper aquifer, just beneath the capping upper aquiclude, averages about 25 feet in thickness - considerably thinner than it is east of the Pleasanton fault in the Santa Rita subbasin (Section C-C', Plate 4).

Since 1944, the water level in the upper aquifer has declined and ground water is no longer extracted from it. In the past, many wells were drilled only into the upper aquifer and these wells flowed under artesian head. Today only one line of such wells remains and is designated by the San Francisco Water Department as the "C" line. These wells were drilled for the Spring Valley Water Company prior to 1912, at the south border of Section 19 in the southwest corner of the subbasin. They are now used by the City of San Francisco as relief wells (they have no pumps) to keep the pressure surface in the upper aquifer some distance below ground surface. This prevents the formation of boggy conditions which, in the past, had affected the production of crops on City-owned property. During occasional periods of high head in the upper aquifer (usually the result of long continued flow in Arroyo del Valle) water rises in the line of wells, flows west in a horizontal header collector pipe set several feet below ground, and can be either discharged to the incised bed of Arroyo de la Laguna or conducted to the Sunol Water Temple through the Pleasanton pipeline.

Since 1923, Artesian conditions in the upper aquifer, which could have produced flow in the "C" line wells, have occurred only during the seven years from 1938 to 1944.

Today, the deeper confined aquifers supply all the ground water pumped from wells in the subbasin. These aquifers are recharged almost exclusively by subsurface inflow through the Pleasanton fault from aquifers in the Santa Rita subbasin. The shape of the pressure surface described by water levels in deep wells shows that the deep aquifers in the Pleasanton subbasin receive no other major source of subsurface recharge. However, a minor source is ground water originating in the Livermore upland to the south which moves northward within the Livermore Formation and then into the alluvium probably at considerable depth.

During the detailed well measurement period in May 1961, the water levels in the upper aquifer stood about 30 feet higher than the deep pressure surface. Water levels in a few shallow wells indicated, during the above measurement period, that a depression in the water surface in the upper aquifer existed near the southern portion of the Pleasanton fault. This depression suggests that the upper aquifer ground water may move downward into the deeper aquifers along the fault zone, through holes in the aquicludes in this area, or around the ends of the aquicludes.

Deep wells are perforated in nearly all the aquifers except the upper one. The static water levels in these deep wells correspond within five feet of each other and are always lower than those in the upper aquifer. The four aquifers in the subbasin are all separated by thick clay aquicludes, which should allow different pressure heads to develop in each aquifer. However, the large number of wells that are perforated in all of the deep aquifers in the subbasin can allow the pressure heads in these aquifers to nearly equalize by interchange of ground water through the well shafts. This would account for the observed small difference in the elevation of the static water levels in deep wells. Moreover, since ground water is not pumped from the upper aquifer and no downward movement of this water can occur through deep wells, water levels in the upper aquifer stand higher.

A narrow portion of valley alluvium extends south from the main part of the subbasin into the narrow canyon of Arroyo de la Laguna (Plate 3). Steep walls rise abruptly on both sides of the relatively flat surface of the alluvium that forms the canyon floor. The alluvium has filled an ancient V-shaped cut eroded in the past in nonwater-bearing rocks such as those exposed in the east wall of the canyon. The cut extends to a depth of 150 feet, or to an elevation of 150 feet above sea level.

Nonwater-bearing rocks forming the west wall of the ancient canyon are concealed beneath a thick portion of the Livermore Formation that appears to have moved down into the canyon as an ancient landslide. The slide area seems to have been intermittently active for a long period of time, but not recently enough to be easily outlined.

Evidence from test drilling and logs of wells west of Verona suggests that the alluvium in the canyon may actually extend westward beneath the old slide for an unknown distance. Thus, while surface evidence 1200 feet south of Verona Road indicates that the alluvium narrows to a width of less than 400 feet between two outcrops of Briones sandstone, the slide may conceal an older and much wider alluvial-filled channel located west of both Foothill Road and the Briones outcrops. The upper aquifer may thus be much wider in the canyon than is indicated by the exposed surface width of the alluvium.

The upper aquifer is the only gravel layer present in the alluvium along the canyon of Arroyo de la Laguna because of the shallowness of bedrock (shown on the left end of section D-D' on Plate 4). Good well log control at Verona Road shows that the upper aquifer is composed of three thin gravel layers separated by thin clay layers. Slight differences in the elevation of water levels measured in the wells at Verona Road indicate that the three gravel layers are not hydrologically interconnected in the immediate vicinity.

Ground water is generally confined within the upper aquifer in the canyon alluvium by the southern extension of the upper aquiclude. However, Arroyo de la Laguna, in cutting the deep trench in which it now flows, has apparently nearly cut through the twenty five-foot thickness of the aquiclude along most of its length. Consequently, in parts of the canyon, creek water is able to recharge the upper aquifer when the water level is depressed, only to receive effluent seepage when the water level is high and the aquifer under pressure.

Water levels in May 1961 showed that ground water moved both north and south as underflow within the confined upper aquifer from local sources of recharge south of Hacienda Road (3S/1E-29P). The unusual concentration of manganese, in excess of one part per million, found in samples of both ground water near Hacienda Road and surface water near Verona Road indicate that effluent seepage to the bed of Arroyo de la Laguna begins near Verona Road.[2/]

Today, ground water in the Pleasanton subbasin (and hence anywhere in the basin) does not escape the basin as subsurface outflow because of the lowered ground water levels resulting from pumping during the last few years. In past years, when the water levels were considerably higher than today, subsurface outflow of ground water within the upper aquifer did occur through the canyon of Arroyo de la Laguna. The deeper confined aquifers never contributed directly to the outflow, since they have no direct connection with the upper aquifer and pinch out along the southern boundary of the subbasin (Plate 4). Instead, once the deep aquifers became fully charged, surplus ground water moved west from the Santa Rita to the Pleasanton subbasin within the upper aqüifer, and then south out the canyon of Arroyo de la Laguna as escaping underflow.

Sunol Valley Ground Water Basin

Within the Sunol Valley ground water basin, ground water occurs, as in the Livermore Valley ground water basin, both in the Livermore Formation and in Quaternary alluvium. The Livermore Formation occurs throughout the Sunol upland and the alluvium occurs only in the Vallecitos, La Costa, and Sunol subbasins (Plates 2 and 3). Virtually all wells in the basin are located in these last three subbasins.

The local availability of surface water from both the Sierra Nevada through the Hetch Hetchy Aqueduct, and the Calaveras Reservoir minimizes the importance of ground water as a source of supply. In addition, the yield of the basin is minor because the producing area is small, the permeable alluvium is thin and confined to the small valleys, and the tight Livermore Formation thinly overlies nonwater-bearing rock.

The general direction of ground water movement appears to be from the Sunol upland toward the major stream valleys, and then westward toward the northwest outlet of the basin.

Sunol Upland

The Sunol upland comprises all exposures of the Livermore Formation in the basin. These exposures surround the Vallecitos and La Costa subbasins and the north portion of Sunol subbasin.

Only two wells are known to produce domestic quantities of ground water in the Sunol upland. The reason there are so few wells is primarily that the yield of the Livermore Formation is low and secondarily that the area is sparsely populated. Most stock water seems to be supplied from runoff and spring flow trapped in many man-made reservoirs located in swales and gullies throughout the Sunol upland.

Recharge of ground water comes from the direct infiltration of runoff and spring flow trapped in the reservoirs mentioned above, and from streams draining across the formation from their sources in the surrounding Sunol highland.

Because of the low infiltration rate of soils covering the Sunol upland (see Plate 9B) most rainfall would rapidly run off without substantial infiltration. However, the number of springs that are evident on topographic maps of the area suggest that rainfall does infiltrate to later emerge in gullies as spring flow. Consequently, the water table must often be roughly coincident with the bottoms of the deeper gullies. This emphasizes the low permeability of the Livermore Formation for, if permeability were high, ground water would drain readily toward the low level of the alluvial subbasins and springs would be absent.

Ground water beneath the Sunol upland most likely moves toward the Sunol, Vallecitos, and La Costa subbasins to supply recharge to the valley alluvium.

The prevailing dip of beds in the Livermore Formation is to the northeast at between 14 and 35 degrees. The permeability of the formation should be highest in the down-dip direction toward Livermore Valley because of the alternating stratification of coarse-grained and fine-grained materials. Therefore ground water would be expected to move in that direction within the relatively tight, confined aquifers of the Livermore Formation. However, the Verona fault may act as a barrier to the movement of ground water to the northeast and largely prevent escape of ground water into the Livermore Valley ground water basin.

Even if the Verona fault were not a barrier, an aquifer exposed near the north edge of the Sunol upland and dipping at only 14 degrees would be located at a depth of several thousand feet beneath the southern edge of Livermore Valley. Consequently, the down-dip movements of ground water in such an aquifer would reach depths in the Livermore Valley ground water basins that would be impractical to tap with wells.

In either case, it is not likely that ground water in the Sunol upland recharges useable portions of the Livermore Valley ground water basin.

Vallecitos Subbasin

The Vallecitos subbasin is the second most productive ground water area in Sunol Valley basin. A total of six wells were present in the subbasin in 1950, the deepest of which was

335 feet. These are all low producing wells used primarily for stock watering and secondarily for domestic supply to a few ranches. The largest water-user in the subbasin is the Vallecitos Atomic Laboratory. However, their entire water demand is supplied from the Hetch Hetchy Aqueduct. One well (4S/1E-2L1) in the subbasin is 283 feet deep but is perforated only above 73 feet. This suggests that the sediments encountered below 73 feet were considered by the driller to be unproductive and are probably part of the Livermore Formation.

The above well log evidence, the small size of the basin, and the known presence of the Livermore Formation underlying the valley all suggest that the alluvium does not exceed 100 feet in thickness.

Analysis of ground water collected from the six wells in the Vallecitos subbasin shows that the quality becomes gradually poorer from approximately 500 parts per million total dissolved solids in the northeast portion of the subbasin to 3,390 ppm TDS (Well 4S/1E-10P1) in the southeast or lowest portion. Moreover, the concentration of boron in well 10P1 is as high as 21 parts per million. This poor quality ground water strongly suggests that Miocene marine formations are buried at shallow depth in the vicinity of the narrow subbasin outlet.

Ground water in the alluvium probably moves from the higher portions of the subbasin toward the southwest outlet and then into the Sunol subbasin. It is very likely that during its southwestern movement, ground water becomes effluent in the lower end of Vallecitos Creek.

The small size of Vallecitos subbasin, the thinness of the alluvium underlying it, and the poor quality of ground water shown to be present in it, all make the subbasin a relatively unimportant part of the Sunol Valley ground water basin.

La Costa Subbasin

The La Costa subbasin is the least important ground water area in the basin. No wells are known to be present in the subbasin and ground water is therefore unused. Since completion of San Antonio Dam, the La Costa subbasin acts merely as part of the recharge area for the reservoir.

The alluvium in the La Costa subbasin probably does not exceed 100 feet in thickness and is underlain by the Livermore Formation. The stream channels of both Indian Creek and San Antonio Creek, located upstream from the reservoir, are underlain by permeable gravel. Stream flow probably percolates into these gravels and moves westerly to discharge into the reservoir as effluent seepage.

The presence of San Antonio Reservoir now largely eliminates the La Costa subbasin as a manageable unit within the Sunol Valley ground water basin.

Sunol Subbasin

The Sunol subbasin is the most productive ground water area in the basin. The four available well logs show that the sediments beneath Sunol Valley are composed largely of sand and gravel with discontinuous layers of clay. Only one of these logs showed any significant thickness of clay near ground surface. This log, a test hole drilled in the bottom of the south filter gallery, reported 16 feet of clay beneath the gallery. This information suggests the presence of a clay aquiclude in the northern portion of the subbasin that may both confine ground water and restrict infiltration of surface water.

The permeable nature of the alluvium in the south portion of the valley is shown on three of the well logs, by the extensive gravel beds in the stream channel of Alameda Creek, and by the presence of off-stream gravel pits (Plate 9B).

Recharge to the Sunol subbasin occurs by infiltration of surface water primarily along Alameda Creek and secondarily along Arroyo de la Laguna, San Antonio Creek, and Vallecitos Creek. Some ground water flows into the alluvium from the Livermore Formation in the Sunol upland but this contribution is minor.

The alluvium in the north portion of the subbasin is underlain by the Livermore Formation. Two of the four well logs reported shale at a depth of 332 feet south of Mission Road near the western edge of the subbasin, and at 167 feet some distance east of the Sunol Water Temple. These two logs suggest that the combined thickness of alluvium and Livermore Formation is not great but that permeable layers are present throughout this thickness.

In the southern portion of the subbasin, the very permeable alluvium is underlain at shallow depth by the nonwater-bearing rocks exposed in the bordering highland.

Extraction of ground water from wells is negligible. Twelve domestic wells producing between 5 and 30 gallons per minute and one irrigation well that produces about 250 gallons per minute were present in the valley in 1950. Orchards and truck crops (largely strawberries) are irrigated with water from the Calaveras Reservoir and much of the domestic demand is supplied by water from the Hetch Hetchy Aqueduct. The largest ground water extractions occur in the Sunol filter galleries.

The Sunol filter galleries consist of a system of underground concrete galleries and pipes buried at depths up to about 15 feet below ground surface and perforated to accept ground water. The galleries extend over 2,000 feet south of the Sunol Water Temple and a greater distance to the north. They have provisions for accepting clear surface water, as well as ground water which is recharged locally in Alameda Creek and Arroyo de la Laguna. Gates throughout the gallery system allow acceptance of water from particular parts of the system. In recent years, the portion of the gallery that once received ground water recharged in Arroyo de la Laguna has been plugged and no longer accepts water from this source. The yield of the galleries is increased by impounding surface water behind Sunol Dam downstream from the galleries.

Based on the well logs previously mentioned, the vicinity of the galleries may be underlain at shallow depth by a clay aquiclude thinly concealed beneath fifteen feet or less of gravel. This would allow only surface water from Alameda Creek to reach the gallery openings by local infiltration through the thin gravel layer. The concealed clay layer would restrict ground water from reaching the galleries directly, when water levels were high, unless ground water flowed over the top of the clay.

Water collected in the Sunol filter galleries, and at the Sunol Water Temple from the Pleasanton well field by way of the Pleasanton pipeline, is conveyed through the Sunol Aqueduct down Niles Canyon to the Niles Reservoir. The aqueduct has a flow capacity of 17,000,000 gallons per day and the Niles Reservoir a storage capacity of 5,000,000 gallons. Water is released from the Niles Reservoir through a 44-inch-diameter steel line extending 2.9 miles southeast to the Irvington pump station. From there it joins the 66- and 60-inch-diameter Hetch Hetchy Aqueduct to San Francisco. At present, Niles Reservoir serves as a regulating reservoir for the Irvington pumps. The alluvial gravels of Sunol Valley thus act to naturally filter the ground water exported from the basin.

Nearly all of Sunol Valley is owned by the City of San Francisco and leased only for crop production. The City uses the valley primarily as a means of filtering and collecting ground water for export. Both Sunol Dam and the filter galleries insure that all but high stream flows passing into the valley are trapped and conveyed out through the Sunol Aqueduct.

Ground water was effluent to the incised channels of both Alameda Creek and Arroyo de la Laguna at the north end of Sunol Valley between December 1958 and March 1960. This was conclusively shown by a series of simultaneous current meter measurements taken at six stations for the Water Rights Board. The effluent portion of the incised creek channels is about 215 feet in elevation or about the same elevation as the bottom of the filter galleries. Therefore, both the galleries and the incised creek beds intercept ground water and prevent it from causing boggy conditions in the soil zone.

Rainfall and stream runoff were well below normal during the above period of effluent seepage[2/] and ground water withdrawal from wells should have been at a peak. Therefore, it is unlikely that the use of ground water is ever sufficient to lower the water table below the bottom of the filter galleries, or 15 feet below ground surface.

The lack of historic ground water depletion and the availability of only a few well logs make it difficult to reliably determine the storage capacity of the Sunol subbasin.

CHAPTER VII. INFILTRATION CHARACTERISTICS OF SURFACE DEPOSITS

Recharge to ground water occurs originally by the downward movement of surface water through surface deposits including soil. The rate of infiltration varies according to the physical characteristics of these deposits. Knowledge of the infiltration rates of surface deposits is helpful in the following ways:

1. To evaluate schemes for artificial recharge.
2. To determine areas where streamflow and rainfall can contribute in varying amounts to the ground water supply.
3. To indicate areas where ground water might be degraded as a result of surface waste discharges.

The infiltration characteristics of the surface deposits in the Livermore Valley and Sunol Valley ground water basins are shown on Plates 9A and 9B. These characteristics are based exclusively on the very recent, and as yet (1965) unpublished soil survey conducted by the U. S. Department of Agriculture, Soil Conservation Service.[17/] The 36 distinct soil classifications that were mapped in the area have been put into 5 groups ranging from very permeable gravel, with an infiltration rate of over 10 inches per hour, to very impermeable plastic clay, with a rate of less than 0.05 inches per hour.

The infiltration characteristics shown on Plate 9 are limited to a depth of 5 feet; however, the soils are often shallower than this and are commonly underlain by more permeable sediments. Where this occurs, the thin soils were included in a more permeable group. Fine-textured soils have a profile usually extending to 5 feet or deeper. This is particularly true of the soils in both the northern and western portions of Livermore Valley.

In the west part of Livermore Valley, fine-textured soils that extend to depths greater than 5 feet are collectively considered to be part of the upper aquiclude, outlined on Plate 9A. Variations in the thickness of the upper aquiclude are shown by the contours on Plate 9A. Contours could not be established in the Parks subbasin and portions of the San Ramon subbasin because of a paucity of well logs.

Well log descriptions indicate that the infiltration characteristics of soil shown on Plate 9A generally represent the characteristics throughout the entire thickness of the upper aquiclude where it is thin. However, in areas where the upper aquiclude is thick, particularly in the northern part of the Santa Rita subbasin and in the Pleasanton subbasin, it should be considered to have a lower infiltration rate equal to the finest-textured group.

The coarser-textured surface deposits are located along the larger stream-courses and in the areas that are worked by man for sand and gravel. The stream-courses are perhaps the most permeable because, by bed agitiation during periods of heavy flow, streams tend to remove fine sediments from between the coarser grains and leave sand and gravel behind.

Gravel pits have been considered by some to be ideal areas for rapid controlled recharge; however, as explained in the following paragraphs, the gravel pits go through a life cycle from development to exhaustion that often renders them as impermeable as the finest-textured soil.

Nearly all of the gravel pits in Livermore Valley are located in the Santa Rita subbasin and are owned and operated by four large companies: Henry J. Kaiser Company; Pacific Cement and Aggregates, Rhodes and Jamieson, and California Rock and Gravel Company.

The gravel pits with the largest area are also the deepest and have been excavated by large dragline or continuous-bucket dredges. These active pits are often partially filled with water because they have been excavated below the water table. The inactive pits often are partially filled with water also, but most of this water comes from the processing plant.

Water used in the processing of gravel (wash water) is pumped both from 12 deep wells on the property of the four gravel companies and from inactive gravel pits in which the water has become clear of suspended solids. Water returning from the processing plant (returned wash water), always heavily laden with clay, silt, and fine sand, is poured into inactive pits where these fine sediments eventually settle out.

Because of the withdrawal of and replenishment to water in various inactive pits, the water level in one pit is seldom coincident with that in another even when they are adjoining. Often, the water levels in the inactive pits are higher than the water table, even though the net gain of returned wash water is small. This occurs because the returned wash water infiltrates through the sand and gravel in the walls and bottoms of the pits and deposits fines between the grains to a depth of a few inches. This filtration process continues until a thick layer of fines is deposited and the initial high rate of infiltration is drastically reduced.

Gravel pits that have long been used as reservoirs for returned wash water have become filled completely to the top with these fines. The older filled pits were originally shallow; however, in 1962, two pits known to have been about 110 feet deep were filled to within a few feet of the ground surface and the filling process was continuing. The infiltration of returned wash water had ceased in these pits and water was eliminated by decantation through an overflow standpipe to adjacent pits where infiltration could still take place. By this procedure, the first pit became the settling basin and the infiltration capacity of the second pit was thereby maintained for a longer period.

The practice of discharging returned wash water to inactive pits will result in the elimination of many pits by backfilling to ground level and will leave many remaining pits useless for recharge as a result of silting.

The infiltration potential of the more permeable flat valley floor areas of the ground water basins will gradually decrease in the future. Residential expansion will eventually cover large areas of permeable soil, thereby decreasing the amount of natural recharge that can occur. This loss may be partially offset by the expansion of gravel pit area, as all the land owned by gravel companies is converted to pits. The future development of gravel pits will be to the north into areas now covered by the thick upper aquiclude. However, as explained above, not all this area will remain permeable after development ceases.

ATTACHMENT 1

BIBLIOGRAPHY

BIBLIOGRAPHY

1. Aarons, B. L. "Geology of a Portion of the Las Trampas Ridge and Hayward Quadrangles, California." Unpublished Masters Thesis, University of California. 1958.

2. California State Department of Water Resources. "Alameda Creek Watershed Above Niles: Chemical Quality of Surface Water, Waste Discharges, and Ground Water". January 1964.

3. California State Department of Water Resources, Division of Design and Construction; South Bay Aqueduct Project, Livermore Valley Division. Phase IV Basic Data Compilation Las Positas Creek Percolation Investigation, April 1960.

4. California State Water Resources Board. "Alameda County Investigation." Bulletin No. 13, Preliminary Edition. July 1955.

5. Clark, B. L. "Tectonics of the Mount Diablo and Coalinga Areas, Middle Coast Ranges of California." Bulletin of the Geological Society of America, Vol. 46, Pt. 2, July 1935.

6. Crittenden, M. D. "Geology of the San Jose-Mount Hamilton Area, California." California Division of Mines. Bulletin No. 157. 1951.

7. Erickson, M. R. : "Geology of the Western Portion of the Pleasanton Quadrangle." Unpublished Masters Thesis, University of California. 1946.

8. Funkhouser, L. W. "The Geology of the Arroyo del Valle Area, Alameda County, California." Unpublished Masters Thesis, Stanford University. 1948.

9. Hall, C. A., Jr. "Geology and Paleontology of the Pleasanton Area, Alameda and Contra Costa Counties, California." University of California Publications in Geological Sciences, Vol. 34, No. 1. 1958.

10. Ham, G. K. "Geology of the Las Trampas Ridge, Berkeley Hills, California." California Division of Mines, Special Report 22. 1952.

11. Harding, J. M., Jr. "The Geology of the Southern Part of The Pleasanton Quadrangle, California." Unpublished Masters Thesis, University of California. 1942.

12. Huey, A. S. "Geology of the Telsa Quadrangle, California." California Division of Mines and Geology. Bulletin No. 140. 1948.

13. Jennings, C. W. and Burnett, J. L. "Geologic Map of California, San Jose Sheet." Preliminary Edition. 1:250,000. 1955

14. Smith, M. B. "Ground Water in the Livermore Valley, California." Unpublished Masters Thesis, Stanford University. 1934.

15. Snow, D. T. "Geology of the Northeast Corner of Alameda County and Adjacent Portions of Contra Costa County." Unpublished Masters Thesis, University of California. 1956.

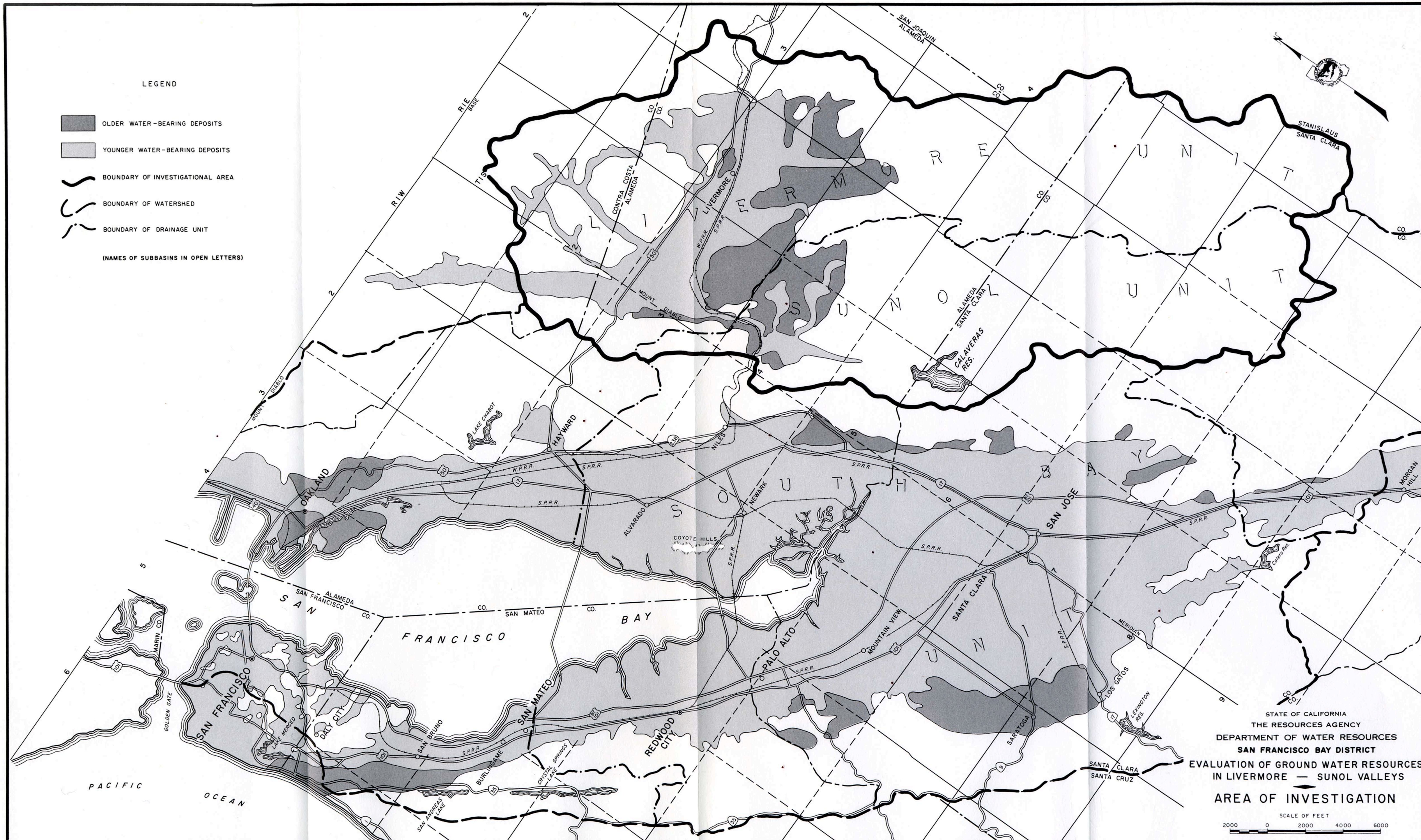
16. Taff, J. A. "Geology of Mount Diablo and Vicinity." Bulletin of the Geological Society of America, Vol. 46, pp. 1079-1100. 1939.

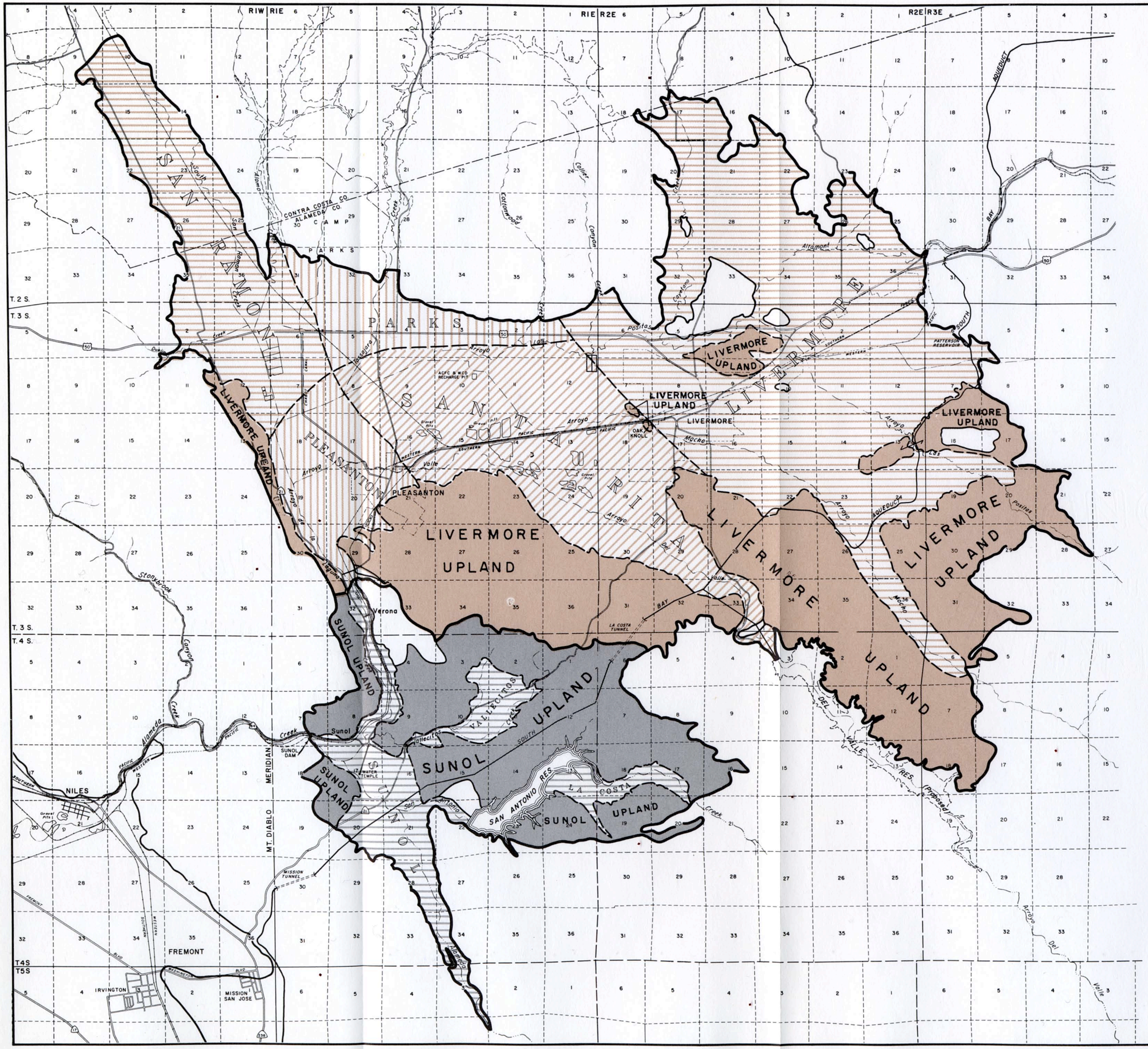
17. U. S. Department of Agriculture, Soil Conservation Service. Unpublished Soil Survey Field Sheets. 1965.

18. Vickery, F. P. "The Structural Dynamics of the Livermore Region." Ph.D. Thesis, Stanford University. 1925.

19. Vickery, F. P. "The Structural Dynamics of the Livermore Region." Journal of Geology, Vol. 33, pp. 608-625. 1925.

20. Westover, H. L. and Van Duyne, C. "Soil Survey of the Livermore Area, California." U. S. Department of Agriculture. 1911.


LEGEND
OLDER WATER-BEARING DEPOSITS
YOUNGER WATER-BEARING DEPOSITS
BOUNDARY OF INVESTIGATIONAL AREA
BOUNDARY OF WATERSHED
BOUNDARY OF DRAINAGE UNIT
(NAMES OF SUBBASINS IN OPEN LETTERS)
LIVERMORE UNIT
SUNOL UNIT
SOUTH BAY UNIT
SAN JOAQUIN
ALAMEDA
STANISLAUS
SANTA CLARA
CONTRA COSTA
ALAMEDA
SAN FRANCISCO
SAN MATEO
SANTA CRUZ
MARIN CO.
MOUNT DIABLO
BASE
MERIDIAN
R1E
R1W
T1S
LIVERMORE
CALAVERAS RES.
LAKE CHABOT
HAYWARD
NILES
OAKLAND
ALVARADO
NEWARK
COYOTE HILLS
SAN JOSE
MORGAN HILL
SANTA CLARA
MOUNTAIN VIEW
PALO ALTO
REDWOOD CITY
SAN MATEO
BURLINGAME
SAN BRUNO
DALY CITY
SAN FRANCISCO
LAKE MERCED
GOLDEN GATE
SARATOGA
LOS GATOS
LEXINGTON RES.
Calero Res.
CRYSTAL SPRINGS LAKE
SAN ANDREAS LAKE
SAN FRANCISCO BAY
PACIFIC OCEAN
W.P.R.R.
S.P.R.R.
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SAN FRANCISCO BAY DISTRICT
EVALUATION OF GROUND WATER RESOURCES
IN LIVERMORE — SUNOL VALLEYS
AREA OF INVESTIGATION
SCALE OF FEET
2000 0 2000 4000 6000



LEGEND

SUNOL VALLEY GROUND WATER BASIN

LIVERMORE VALLEY GROUND WATER BASIN

VALLEYS
UNDERLAIN BY QUATERNARY ALLUVIUM

UPLANDS
UNDERLAIN BY THE LIVERMORE FORMATION

GROUND WATER BASIN BOUNDARY

GROUND WATER SUBBASIN BOUNDARY
(NAMES OF SUBBASINS IN OPEN LETTERS)

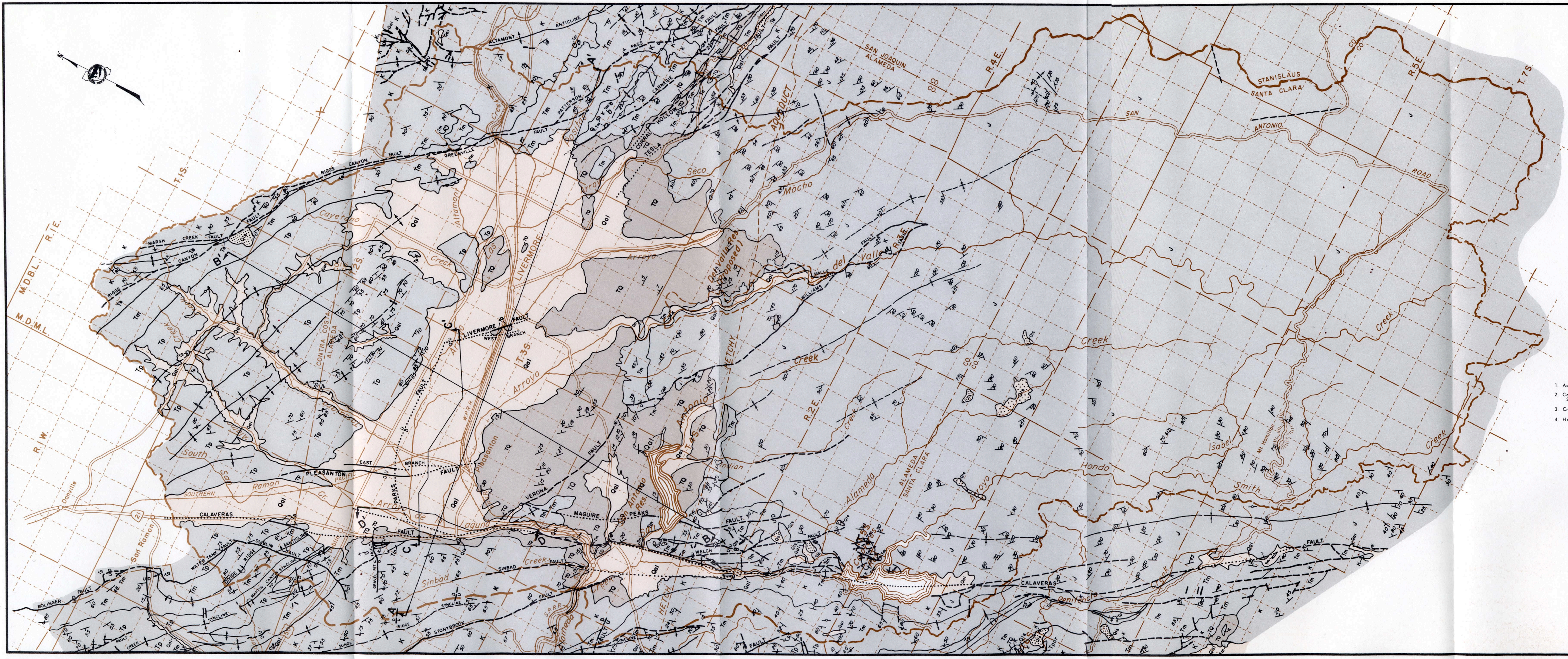
STATE OF CALIFORNIA
THE RESOURCES AGENCY

DEPARTMENT OF WATER RESOURCES
SAN FRANCISCO BAY DISTRICT

EVALUATION OF GROUND WATER RESOURCES
IN LIVERMORE — SUNOL VALLEYS

LOCATION OF SUBBASINS WITHIN THE LIVERMORE AND SUNOL VALLEYS GROUND WATER BASINS

SCALE OF FEET
4000 0 4000 8000 12000



LITHOLOGIC UNITS

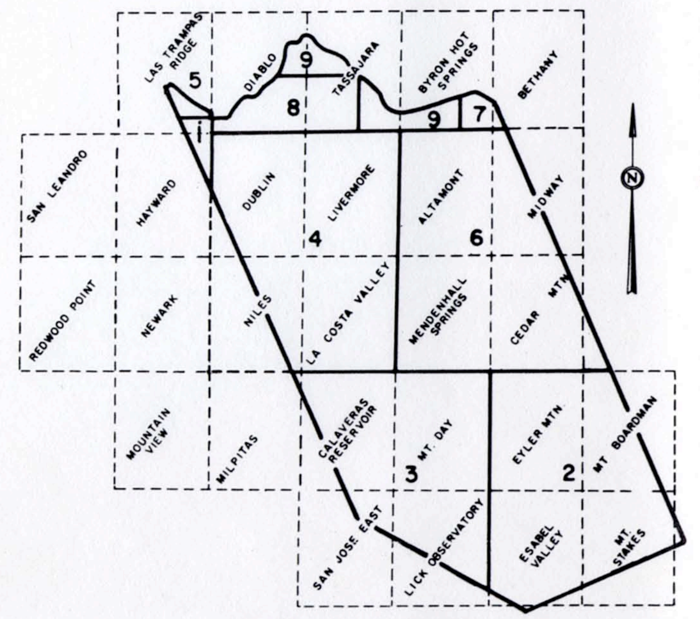
QUATERNARY — RECENT; PLEISTOCENE

TERTIARY — PLIOCENE; MIOCENE; EOCENE

CRETACEOUS

JURASSIC

Qls	**LANDSLIDE DEPOSITS**	
Qal	**QUATERNARY ALLUVIUM** CONTINENTAL GRAVEL, SAND, SILT, AND CLAY.	UNCONSOLIDATED WATER BEARING DEPOSITS
TQ	**UNDIFFERENTIATED TERTIARY – QUATERNARY DEPOSITS INCLUDING LIVERMORE GRAVELS AND SANTA CLARA GRAVELS** CONTINENTAL GRAVEL, SAND, AND CLAY, WITH SOME TUFF	SEMICONSOLIDATED WATER BEARING DEPOSITS
Tpar	**ALUM ROCK RHYOLITE** FLOWS AND INTRUSIVE DOMES.	SEMICONSOLIDATED TO CONSOLIDATED ESSENTIALLY NON-WATER BEARING ROCKS.
Tp	**UNDIFFERENTIATED PLIOCENE FORMATIONS** CONTINENTAL CONGLOMERATE, SANDSTONE, CLAYSTONE, TUFF, AND SOME LIMESTONE LENTILS. OFTEN CEMENTED.	
Tm	**UNDIFFERENTIATED MIOCENE FORMATIONS** MARINE SANDSTONE, SHALE, CONGLOMERATE, AND SOME TUFF OFTEN FOSSILIFEROUS.	
Te	**UNDIFFERENTIATED EOCENE FORMATIONS** MARINE SANDSTONE, CLAY, AND SHALE, OCCASIONAL COAL SEAMS AND CONGLOMERATE BEDS.	
K	**UNDIFFERENTIATED CRETACEOUS FORMATIONS** MARINE SANDSTONE, SILTSTONE, SHALE, AND CONGLOMERATE.	
J	**UNDIFFERENTIATED KNOXVILLE FORMATION AND FRANCISCAN GROUP** MARINE SANDSTONE, SHALE, AND CHERT; WITH SOME CONGLOMERATE AND LIMESTONE LENTILS; AND RELATED BASALT, SERPENTINE AND SCHIST.	



INDEX TO GEOLOGIC MAPPING
(Most Sources Modified)

1. Aarons, B. L., 1958.
2. California Division of Mines and Geology, Preliminary San Jose Sheet.
3. Crittenden, M. D., 1951.
4. Hall, C. A. Jr. 1958.
5. Ham, C. K., 1952.
6. Huey, A. S., 1948.
7. Snow, D. T., unpublished.
8. Thomas, R. G., Alameda County Investigation
9. Taff, J. A., 1939.

GEOLOGIC SYMBOLS

- LITHOLOGIC CONTACT, LOCATION APPROXIMATE.
- U / D — FAULT, LOCATION KNOWN (U – UPTHROWN SIDE; D – DOWNTHROWN SIDE; ARROWS SHOW RELATIVE DIRECTION OF HORIZONTAL MOVEMENT).
- U / D — FAULT, LOCATION APPROXIMATE.
- U / D — FAULT, LOCATION INFERRED.
- AXIS OF ANTICLINE, SHOWING PLUNGE.
- AXIS OF OVERTURNED ANTICLINE.
- AXIS OF SYNCLINE, SHOWING PLUNGE.
- AXIS OF OVERTURNED SYNCLINE.
- 70 — STRIKE AND DIP OF BED.
- 80 — STRIKE AND DIP OF OVERTURNED BED.
- A A' — GEOLOGIC SECTION.

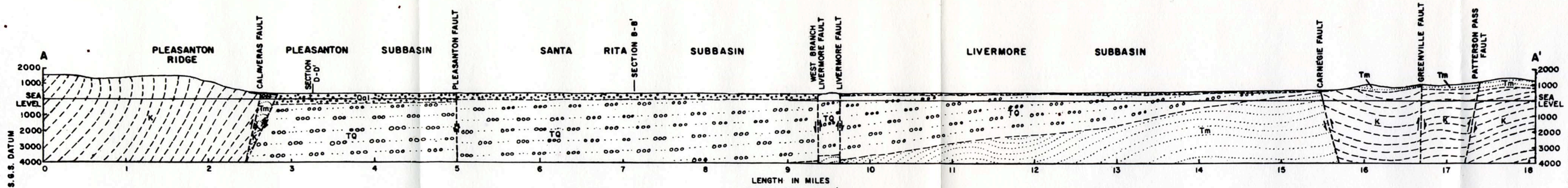
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SAN FRANCISCO BAY DISTRICT

EVALUATION OF GROUND WATER RESOURCES IN LIVERMORE — SUNOL VALLEYS

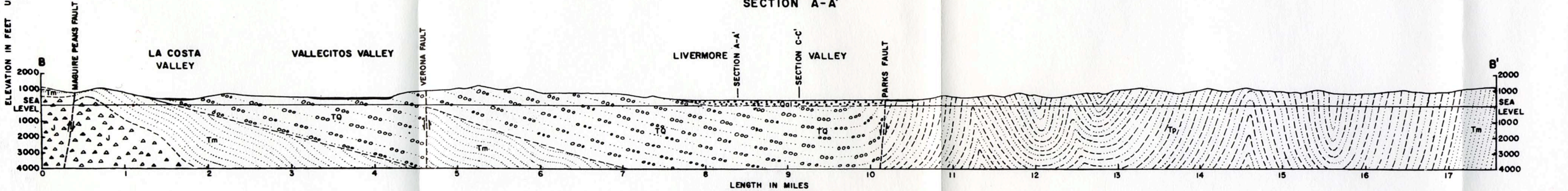
AREAL GEOLOGY

SCALE OF MILES

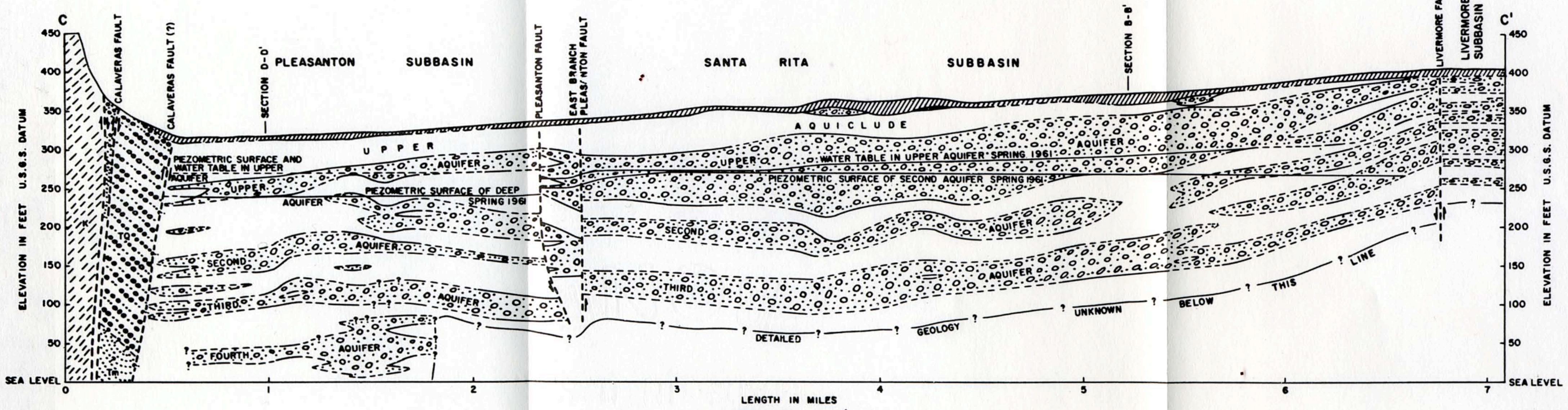
0 2 4



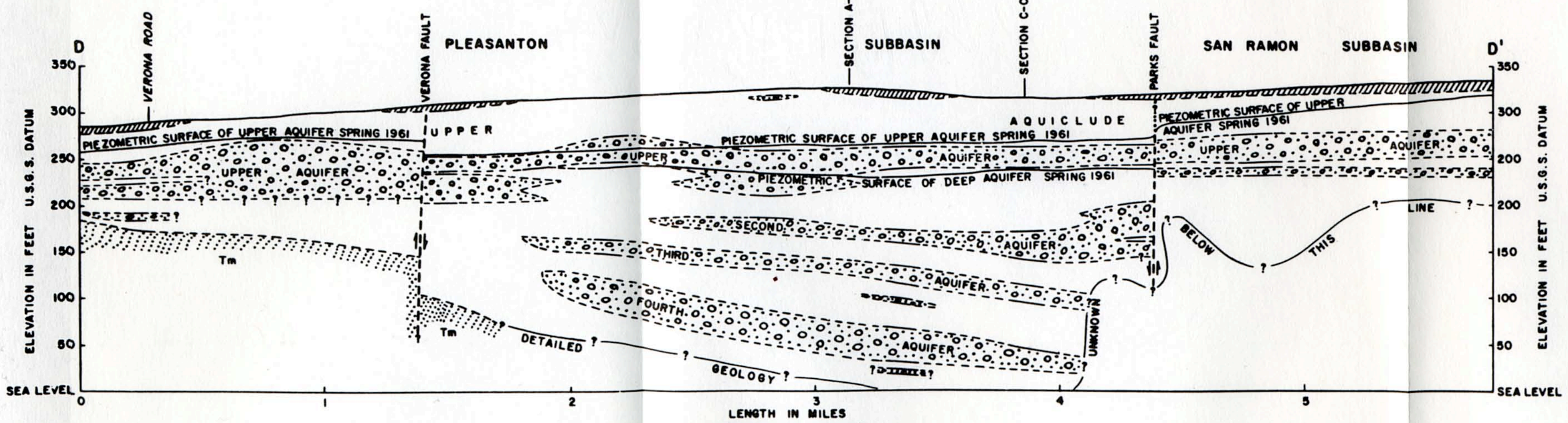
SECTION A-A'



SECTION B-B'



SECTION C-C'



SECTION D-D'

LEGEND

STRATIGRAPHIC SYMBOLS FOR SECTIONS A-A' TO C-C'

Qal	QUATERNARY ALLUVIUM	WATER BEARING DEPOSITS
TQ	TERTIARY-QUATERNARY LIVERMORE FORMATION	WATER BEARING DEPOSITS
Tp	PLIOCENE DEPOSITS	NON-WATER BEARING DEPOSITS
Tm	MIOCENE ROCKS	NON-WATER BEARING DEPOSITS
K	CRETACEOUS ROCKS	NON-WATER BEARING DEPOSITS
	JURASSIC ROCKS	NON-WATER BEARING DEPOSITS

LITHOLOGIC SYMBOLS FOR SECTIONS C-C' TO D-D'

SOIL

GRAVEL OR SAND AND GRAVEL (AQUIFERS).

SAND (AQUIFERS).

CLAY, SILT, SANDY CLAY (AQUICLUDES).

CONTACT, DASHED WHERE APPROXIMATELY LOCATED, QUERIED WHERE UNCERTAIN.

FAULT, SHOWING DIRECTION OF RELATIVE MOVEMENT.

NOTE: SEE PLATE 3 FOR LOCATION OF SECTIONS.

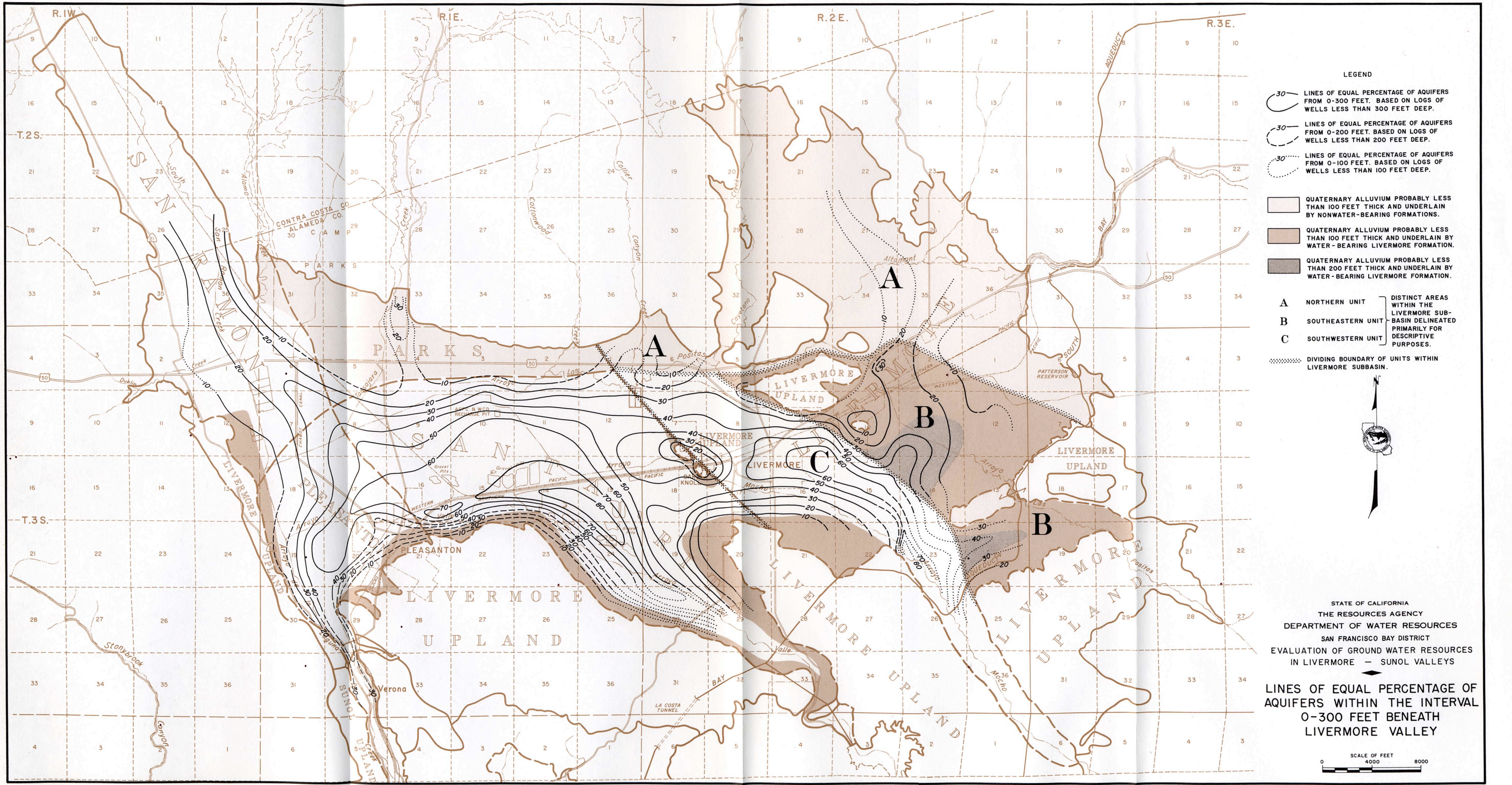
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SAN FRANCISCO BAY DISTRICT

EVALUATION OF GROUND WATER RESOURCES IN LIVERMORE-SUNOL VALLEY

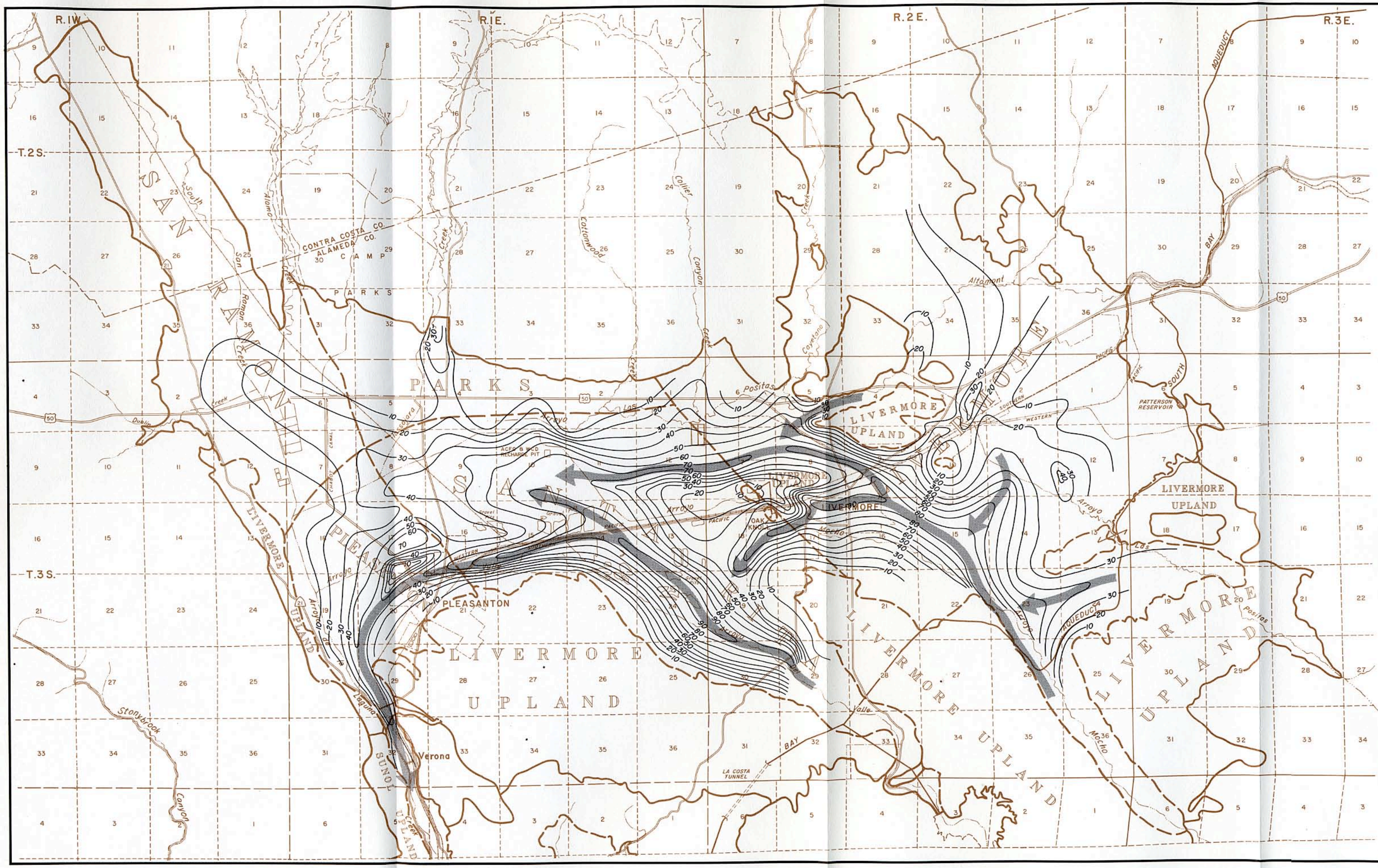
GEOLOGIC SECTIONS - LIVERMORE VALLEY

SHOWING STRATIGRAPHIC RELATIONS, STRUCTURE AND LITHOLOGY

PLATE 5

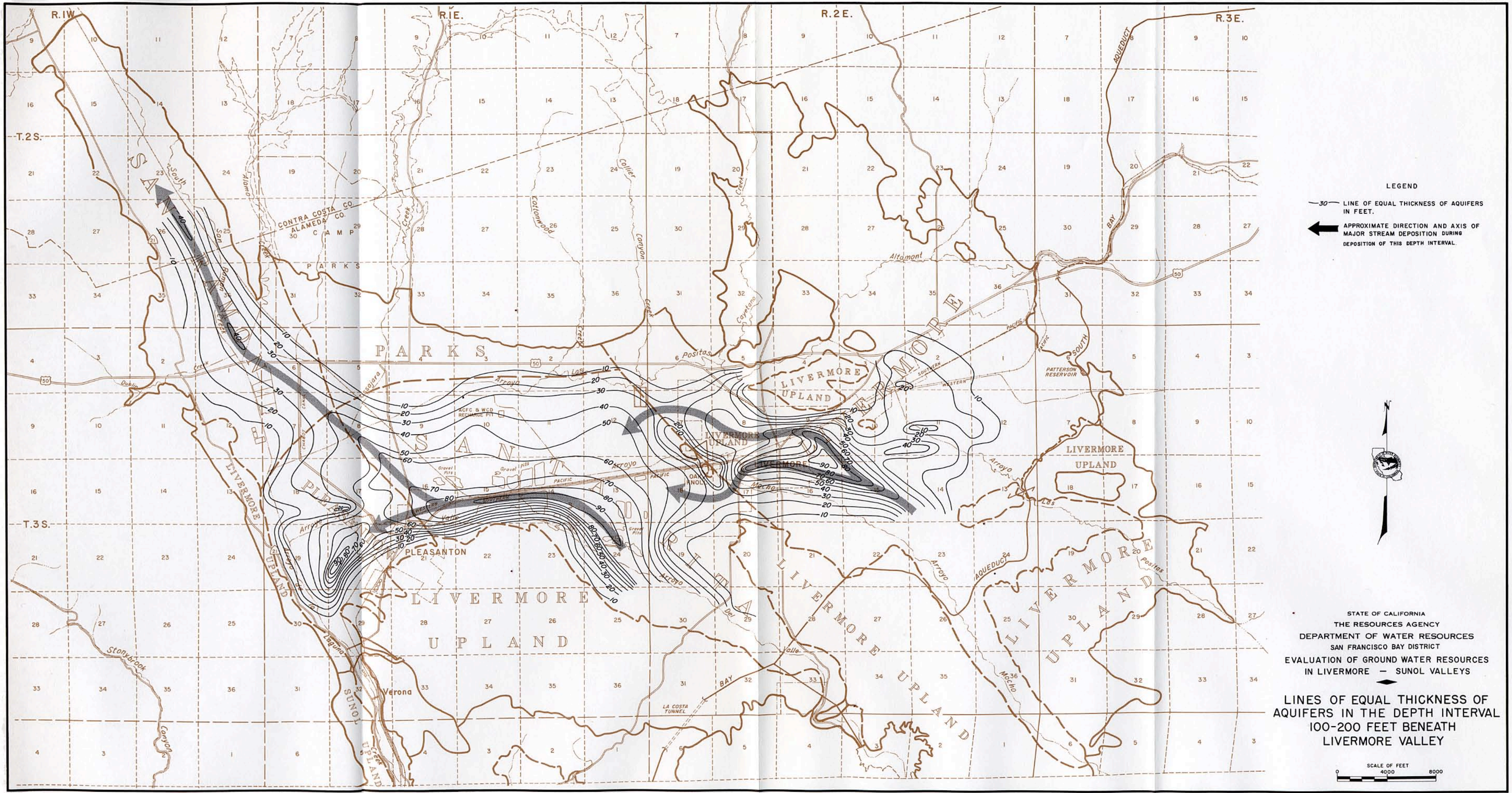


LEGEND
LINES OF EQUAL PERCENTAGE OF AQUIFERS FROM 0-300 FEET. BASED ON LOGS OF WELLS LESS THAN 300 FEET DEEP.
LINES OF EQUAL PERCENTAGE OF AQUIFERS FROM 0-200 FEET. BASED ON LOGS OF WELLS LESS THAN 200 FEET DEEP.
LINES OF EQUAL PERCENTAGE OF AQUIFERS FROM 0-100 FEET. BASED ON LOGS OF WELLS LESS THAN 100 FEET DEEP.
QUATERNARY ALLUVIUM PROBABLY LESS THAN 100 FEET THICK AND UNDERLAIN BY NONWATER-BEARING FORMATIONS.
QUATERNARY ALLUVIUM PROBABLY LESS THAN 100 FEET THICK AND UNDERLAIN BY WATER-BEARING LIVERMORE FORMATION.
QUATERNARY ALLUVIUM PROBABLY LESS THAN 200 FEET THICK AND UNDERLAIN BY WATER-BEARING LIVERMORE FORMATION.
A NORTHERN UNIT
B SOUTHEASTERN UNIT
C SOUTHWESTERN UNIT
DISTINCT AREAS WITHIN THE LIVERMORE SUB-BASIN DELINEATED PRIMARILY FOR DESCRIPTIVE PURPOSES.
DIVIDING BOUNDARY OF UNITS WITHIN LIVERMORE SUBBASIN.
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SAN FRANCISCO BAY DISTRICT
EVALUATION OF GROUND WATER RESOURCES IN LIVERMORE — SUNOL VALLEYS
LINES OF EQUAL PERCENTAGE OF AQUIFERS WITHIN THE INTERVAL 0-300 FEET BENEATH LIVERMORE VALLEY
SCALE OF FEET
0 4000 8000
R.1W.
R.1E.
R.2E.
R.3E.
T.2S.
T.3S.
SAN RAMON
PARKS
CAMP PARKS
CONTRA COSTA CO.
ALAMEDA CO.
LIVERMORE UPLAND
SANTA RITA
LIVERMORE
PLEASANTON
Verona
SUNOL UPLAND
PATTERSON RESERVOIR
LA COSTA TUNNEL



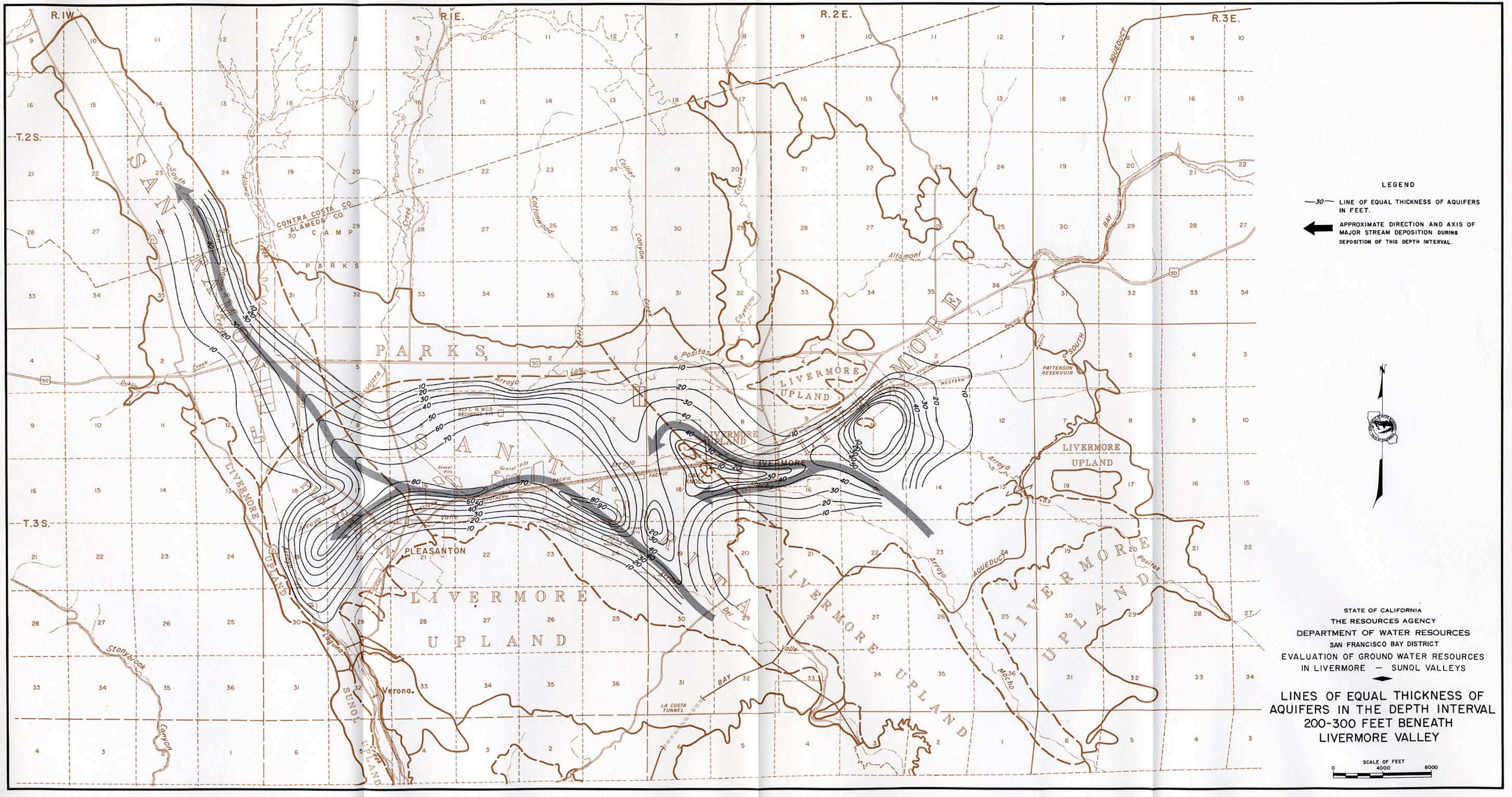
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SAN FRANCISCO BAY DISTRICT
EVALUATION OF GROUND WATER RESOURCES
IN LIVERMORE — SUNOL VALLEYS

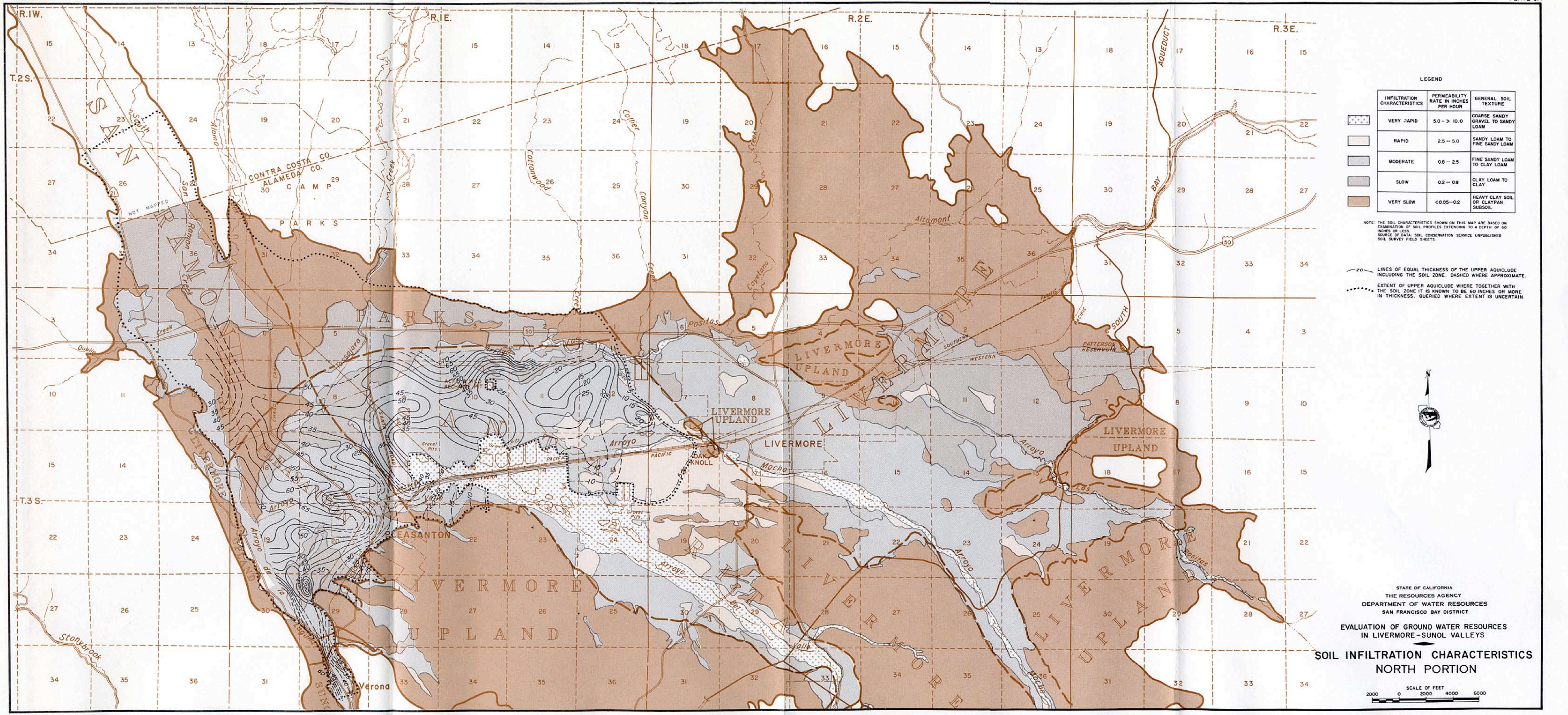
LINES OF EQUAL THICKNESS OF AQUIFERS IN THE DEPTH INTERVAL 0-100 FEET BENEATH LIVERMORE VALLEY



STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SAN FRANCISCO BAY DISTRICT
EVALUATION OF GROUND WATER RESOURCES
IN LIVERMORE — SUNOL VALLEYS

LINES OF EQUAL THICKNESS OF AQUIFERS IN THE DEPTH INTERVAL 100-200 FEET BENEATH LIVERMORE VALLEY


LEGEND
—30— LINE OF EQUAL THICKNESS OF AQUIFERS IN FEET.
APPROXIMATE DIRECTION AND AXIS OF MAJOR STREAM DEPOSITION DURING DEPOSITION OF THIS DEPTH INTERVAL.
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SAN FRANCISCO BAY DISTRICT
EVALUATION OF GROUND WATER RESOURCES IN LIVERMORE — SUNOL VALLEYS
LINES OF EQUAL THICKNESS OF AQUIFERS IN THE DEPTH INTERVAL 200-300 FEET BENEATH LIVERMORE VALLEY
SCALE OF FEET
0 4000 8000
R.1W.
R.1E.
R.2E.
R.3E.
T.2S.
T.3S.
LIVERMORE UPLAND
PLEASANTON
Verona.
PATTERSON RESERVOIR
ALCFC & WCD RECHARGE PIT
LA COSTA TUNNEL
CONTRA COSTA CO.
ALAMEDA CO.
CAMP PARKS



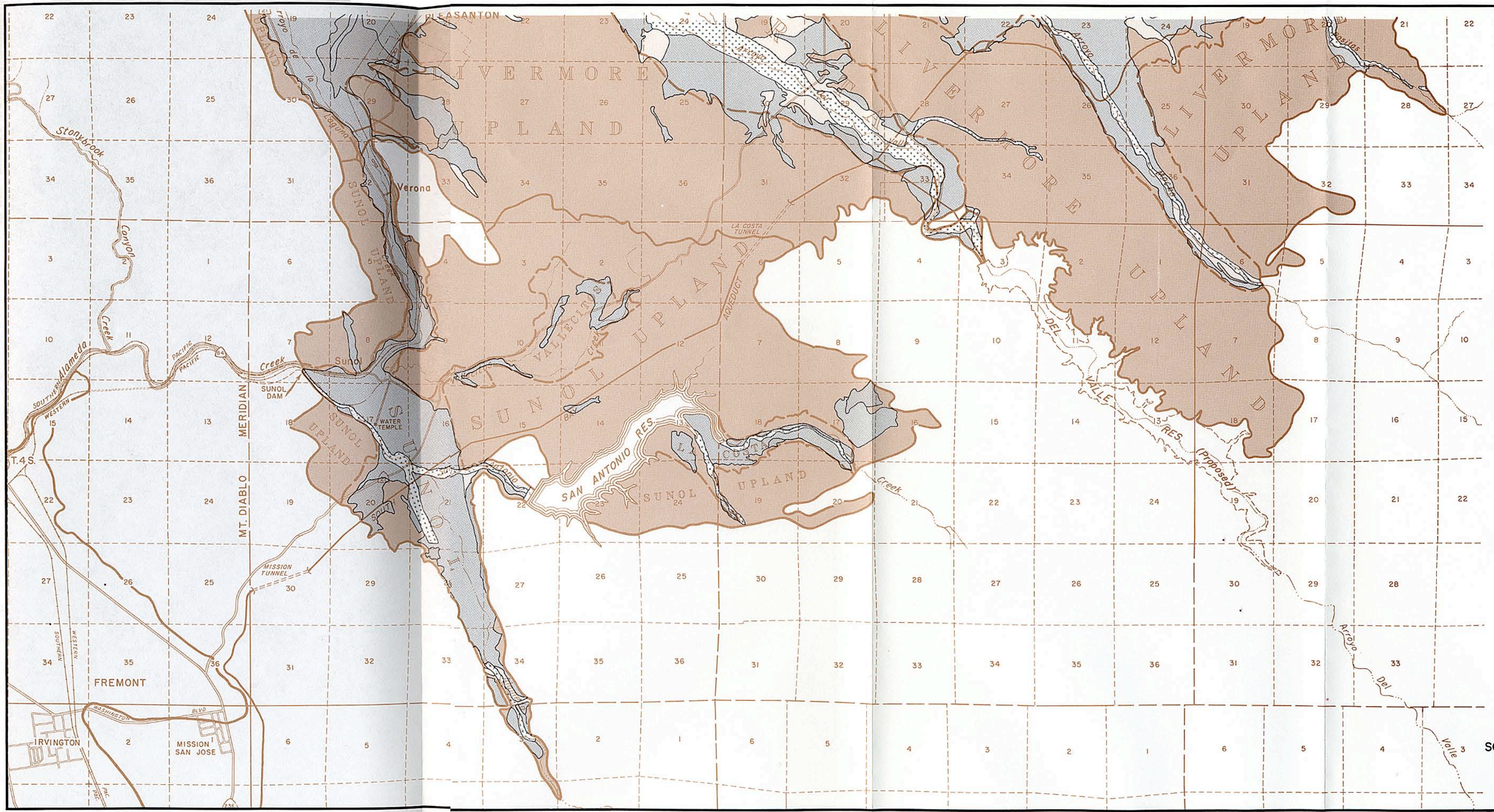
INFILTRATION CHARACTERISTICS	PERMEABILITY RATE IN INCHES PER HOUR	GENERAL SOIL TEXTURE
VERY RAPID	5.0 —> 10.0	COARSE SANDY GRAVEL TO SANDY LOAM
RAPID	2.5 — 5.0	SANDY LOAM TO FINE SANDY LOAM
MODERATE	0.8 — 2.5	FINE SANDY LOAM TO CLAY LOAM
SLOW	0.2 — 0.8	CLAY LOAM TO CLAY
VERY SLOW	<0.05—0.2	HEAVY CLAY SOIL OR CLAYPAN SUBSOIL

NOTE: THE SOIL CHARACTERISTICS SHOWN ON THIS MAP ARE BASED ON EXAMINATION OF SOIL PROFILES EXTENDING TO A DEPTH OF 60 INCHES OR LESS.
SOURCE OF DATA: SOIL CONSERVATION SERVICE UNPUBLISHED SOIL SURVEY FIELD SHEETS.

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SAN FRANCISCO BAY DISTRICT

EVALUATION OF GROUND WATER RESOURCES IN LIVERMORE-SUNOL VALLEYS

SOIL INFILTRATION CHARACTERISTICS
NORTH PORTION



LEGEND

INFILTRATION CHARACTERISTICS	PERMEABILITY RATE IN INCHES PER HOUR	GENERAL SOIL TEXTURE
VERY RAPID	5.0 -> 10.0	COARSE SANDY GRAVEL TO SANDY LOAM
RAPID	2.5 — 5.0	SANDY LOAM TO FINE SANDY LOAM
MODERATE	0.8 — 2.5	FINE SANDY LOAM TO CLAY LOAM
SLOW	0.2 — 0.8	CLAY LOAM TO CLAY
VERY SLOW	<0.05—0.2	HEAVY CLAY SOIL OR CLAYPAN SUBSOIL

NOTE: THE SOIL CHARACTERISTICS SHOWN ON THIS MAP ARE BASED ON EXAMINATION OF SOIL PROFILES EXTENDING TO A DEPTH OF 60 INCHES OR LESS.
SOURCE OF DATA: SOIL CONSERVATION SERVICE UNPUBLISHED SOIL SURVEY FIELD SHEETS.

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SAN FRANCISCO BAY DISTRICT

EVALUATION OF GROUND WATER RESOURCES
IN LIVERMORE-SUNOL VALLEYS

SOIL INFILTRATION CHARACTERISTICS
SOUTH PORTION

SCALE OF FEET
2000 0 2000 4000 6000